# ECOLOGY, BEHAVIOUR AND INTEGRATED CONTROL OF CABBAGE INSECT PESTS IN TASMANIA

by

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HOBART

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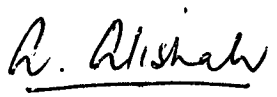
"TO:

ALL SHORT-LIVED CHILDREN

WHO SUFFER AND LEAVE US

WITH LONG-LASTING MEMORIES."

This thesis does not contain any material which has been accepted for the award of any other higher degree or graduate diploma in any tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by any other person, except where due reference is made in the text of this thesis.



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**ABSTRACT**

The cabbage white butterfly (CWB), diamondback moth (DM) and cabbage aphid (CA) are the most important pests of brassica crops in Tasmania.

The basic biology and ecology of these pests were studied in laboratory and field experiments and commercial cabbage crops. Key biotic and abiotic factors influencing the seasonality and abundance were identified by regular sampling. Populations of CWB and DM were markedly seasonal with maximum densities recorded in December-January. In contrast, CA persisted in cabbage fields throughout the year and was the most abundant in spring and autumn. Number of generations of each species was related to the amount of heat they experienced as measured by degree-days and were 5, 5 and 13 for CWB, DM and CA respectively. Direct counts of insects per plant were the most reliable measure of abundance as conventional trapping techniques sampled insects in general flight rather than the population on the crops. Natural enemies were insignificant factors in population regulation.

In the examination of the insect-plant interaction, the cabbage plant was classified into 6 readily identifiable growth stages, the development of which required a specific number of degree-days. The cabbage plant was able to compensate for insect damage however, attack by CWB at cupping, DM at early cupping, and pre heading and CA at post seedling, cupping and pre heading

resulted in irreversible losses in vegetative growth and final marketable product. Plant sensitivity to defoliation is discussed in relation to the growth and development pattern of cabbage plant.

Regular insecticide sprays promoted pest resurgence while lack of sanitation e.g. non-removal of crop wastes and residues, inappropriate insecticides and time of applications were found to be common features in commercial fields that aggravated pest status. A beneficial consequence of this study was that regular monitoring of crop and destruction of stubbles and crop residues became part of the commercial grower's programme. Criteria for spraying decisions were developed based on the kind and frequency of chemicals employed, the plant growth stage and the density and stage of the respective pests.

Integrated control schedules including chemical insecticides and bacterial, fungal and nematode pathogen formulations were compared to recommended spray schedules. Although less damaging to natural enemies these alternative treatments were unreliable being dependent on appropriate plant growth stage and environmental conditions for effectiveness. Resource partitioning in multipest infestations was observed and the unilateral impact of infestation on plant economy was quantified. Spray application decisions based on plant stage and minimum damaging pest levels provided economic control for a lower cost.

Oviposition and larval damage of lepidopterans were

directly related to the degree of waxiness of cabbage cultivars. In contrast, CA was not affected by waxes but utilizes an alternative strategy involving direct testing (probing) and plant water status. Non-preference was the dominant mode of cabbage plant resistance to pest infestation.

Experimental disruption of the leaf wax bloom by solvent sprays or systemic wax inhibitors was found to suppress oviposition and larval feeding in CWB and DM and alate colonization and larviposition by CA. The physiological and chemical basis of this phenomenon was investigated and it is hypothesized that CWB and DM behaviour is modified by changes in levels of wax components notably alkanes, ketones, alcohols, aldehydes and the triterpenoids $\alpha$ and $\beta$ amyrin while CA is directly influenced by water status of plant as determined by probing.

In summary, this dissertation provides :

(i) a practical appraisal of cabbage pest control in terms of materials employed and cultural practices and makes recommendations for decision making related to pest infestation levels and plant growth stage and ;

(ii) an alternative explanation to the mechanism of host plant selection by insect pests.

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# CHAPTER 1

# INTRODUCTION

Insects are regarded as the most successful arthropods because of their high rates of reproduction and characteristic adaptability to diverse ecological situations. Those species which infest plants have gone through a long period of coevolution with their hosts by adopting a variety of associations with them. Some insects are regarded as pests because they interfere with man's welfare, property and aesthetic values, causing economic losses.

Agricultural pests cause losses by reducing either the quantitative or qualitative efficiency of a production system (Southwood and Norton, 1973) i.e. they reduce productivity and economic value of the product through direct feeding, contamination or by introducing pathogens or toxic metabolites into their hosts.

Global demands for food and fibre have necessitated increases in farm yields which, in many instances, depend on insecticides to protect against recurrent pest attack. As a consequence, remarkable gains in yields have been achieved, permitting a more diversified and intensive agriculture (Eichers, 1981). However, continuous use of insecticides has promoted an increased incidence of pest resistance, outbreaks of secondary pests and destruction of natural enemies with serious economic and ecological consequences (Carson, 1962; van den Bosch and Messenger, 1973; Merril, 1976; Pimentel et al., 1978).

The optimistic view of modern insecticides as simple and permanently effective means of pest control has not been upheld and their continued use is a question of debate (Metcalf, 1980). Interestingly, in the United States, crop losses due to insect pests during 1942-1974 nearly doubled, from 7 to about 13%, despite a 10-fold increase in the use of pesticides and the use of high yielding varieties and increased application of fertilizer (Pimentel, 1978).

Nevertheless, insect pest control is crucial for efficient agricultural productivity. Presently, the banning of all pesticides would be disastrous as crop losses could soar to 25-50% with a 4-5 fold rise in the price of food (Borlaug, 1972). So a major decline in the use of pesticides in the foreseeable future would seem ambivalent. However, continued reliance upon pesticides is of mounting concern to both developed and developing countries because high costs are involved in their manufacture from already declining and unrenewable fossil fuels.

The recent history of chemical pest control indicates a variety of ecological problems associated with the application of a pesticide without any regard to pest incidence. Unfortunately, demand for high quality and blemish-free product promotes this practice amongst farmers to the present day.

It is an established fact that a lack of ecological information of a pest situation perpetuates our reliance on chemical control measures. Thus there is always a need

for a complete understanding of a pest's ecology which determines the mechanism of population distribution and abundance in time and space and by how much species attributes are affected by both biotic and abiotic components of the environment. Such environmental components play an important role in the dynamics of insect populations. Population studies should be based upon an acceptable estimate of the size of the population. For this purpose methods have been suggested depending on the species, habitat type and life stage of insects (Southwood, 1966).

Although knowledge of population dynamics is vital for pest control strategies, it is of little use without an insight into the relationship between the insect infestation and its impact on growth and yield of the plant. For a thorough understanding of this relationship Bardner and Fletcher (1974) have categorized these factors into :

1. Constant factors : which include growth pattern of the plant or crop and the nature of injuries and their distribution on and between plants;
2. Variable factors : which include the time of attack in relation to plant growth, the intensity of injuries, the duration of attack and the effect of environmental factors on plant or crop growth.

Thus a critical understanding of these relationships is very important in assessing the need for and

methodology of pest control operations.

Insect infestations usually cause a loss in productivity but there are certain examples which have revealed that insects can sometimes cause a decrease in quality without decreasing marketable yields (Ordish and Toft, 1965). On the other hand a plant can either ;

a. tolerate or compensate quantitative damage without reducing yield (Bardner and Fletcher, 1974) or
b. overcompensate the damage with an increase in the yield (Harris, 1974).

The impact of a herbivore can also be reduced through modifying plants external environment or metabolism (McNaughton, 1983), by accelerating plant growth (e.g. Samson and Geier, 1983) by the induction of inherent chemical defenses (Beck, 1965; Levin, 1976) or by imparting resistance (tolerance and antibiosis) against the herbivore´s attack (Painter, 1951). Once these aspects are defined for any particular plant-herbivore interaction, judicious pest control measures can be devised.

At present, rigorous attempts are being made to avoid the use of insecticides as well as search for suitable alternatives that could easily be integrated into the agroecosystem. For this reason there has been an increased interest in the development and use of microbial pest control methods. Moreover, due to the increasing realization of the value of natural enemies and pathogens,

it seems imperative to develop integrated control programmes which maximize the effects of natural control agents to reduce our dependence on chemical pest control operations.

A number of insect species, hereafter termed cabbage pests, are the major limiting factors to brassica vegetable production in Tasmania and mainland Australia. These "specialist pests" include cabbage aphid, Brevicoryne brassicae (L.) (Homoptera : Aphididae); cabbage white butterfly, Artogeia rapae (L.) (Lepidoptera : Pieridae); and diamondback moth, Plutella xylostella (L.) (Lepidoptera : Yponomeutidae). Cabbage aphid feeds on the phloem sap of plant, forms its colonies and seriously contaminates the product. Cabbage white butterfly larvae feed on foliage and also contaminate the product with their excrement. Similarly, diamondback moth larvae feed on leaves and tunnel into the product.

Commercial growers in Tasmania and South Australia use fixed-scheduled insurance sprays to ensure protection from expected pest attacks. The vegetable processing industry demends a pest free product i.e. zero pest tolerance. Commercial vegetable growers regard insecticides as a simple, effective and reliable means of control despite their cost and the need for frequent applications whether or not pests are present. This problem is more acute among brassica vegetable growers in the North-West coast region of Tasmania.

Questions are often raised by the public at large about the timing, frequency and the residual persistence

of the toxicants applied on short duration brassica vegetable crops whose product is usually consumed either fresh or after light cooking or processing.

The lack of detailed knowledge regarding seasonality, crop-pest-yield relationships and the potential of integrated pest control prompted the need for a biorational investigation of the ecology and integrated control of brassica pests in Tasmania.

The cabbage (Brassica oleracea var capitata (L.) ) was used in this study as it provided cultures throughout the year, distinctive growth and developmental stages and continuous incidence/infestation by one or more of three pest species. The damaging stages of these pests are not very mobile on the cabbage plant which made their counting, sampling and comparisons of experimental treatments easier. All of these attributes offered a comprehensive rationale for ecological and applied control evaluations.

It was difficult to cover all the ecological aspects of three pests because of the complexity of possible interactions involved in and between their behavioural patterns. Therefore, the ecological part of this study was centred around their seasonal distribution and abundance in relation to phenological characteristics of the cabbage host.

Relationships between population maxima and certain environmental parameters, with particular emphasis on the physiological time scale, were also established. Natural populations of adult insects were determined by field

trapping e.g. sticky traps, water traps and pheromone traps.

An important feature of this study was the comparison of information on cropping pattern, cultural practices, and pest dynamics under a range of conventional crop protection measures and their economies. This was achieved through regular visits to two commercial grower's farms and the information collected was used as a benchmark to compare different applied control strategies in replicated research plots during 1982-85.

Investigations were also conducted to understand the relationship between insect infestation and their effect on the growth and yield forming process of cabbage plants. This was examined through field assessments and laboratory experimentations.

The efficacy of selective registered insecticides, used alone or in combination with other chemicals and/or microbial insecticides, was evaluated in relation to the need, timing and frequency of required standards of integrated control strategies.

Laboratory and field evaluations were conducted on the potential use of entomopathogenic nematodes, bacteria and fungi in suitable formulation to enhance their survival and efficiency under field conditions.

Field studies on the relative resistance of seven commercial cabbage cultivars to pest attack were conducted with a particular focus on pest abundance, compensation to insect damage/infestations, damage assessments and their overall performance in forms of duration of growth and

their yield and marketability.

Finally, this study investigated the effect of disruption of leaf wax bloom and alteration of cabbage plant physiology and pest response. Evaluations of the involved mechanism, efficacy and cost effectiveness of this approach were made through a series of laboratory and field experiments.

The theoretical and applied nature of this study adheres to the philosophy of safer and more effective integrated control methods and this is, therefore, relevant to the economic and environmental implications of today´s pesticidal control i.e. to devise a more effective and less environmentally disturbing use of pesticides, to control cabbage pests.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 General

Plant species are subject to attacks by herbivorous insects at all stages of their growth and insect outbreaks can result in severe economic losses. Such herbivorous insects have undergone a long and varied period of coevolution with their host plants and have developed different patterns of association coupled with different life cycle strategies and feeding mechanisms (Hodkinson and Hughes, 1982).

The feeding mechanisms involve sap sucking, leaf chewing or feeding on stem, root, seed or fruit. Furthermore, in relation to its host range, any insect herbivore may be grouped as monophagous, oligophagous or polyphagous (e.g. Eastop, 1973; Pitkin, 1976; Slansky, 1976; Janzen, 1980).

Plant species possess a wide range of defensive adaptations that minimize the impact of herbivory by the insect. These defenses include physical characteristics such as the nature of the cuticle, leaf hairs and texture (Feeny, 1970; Levin, 1973; Pillemer and Tingey, 1978) and secondary metabolites of the plant which apparently do not play any major role in the physiology of the plant but have been implicated in the defense of the plant (Robinson, 1979).

All members of cruciferae contain glucosinolates which

are hydrolysed by a thioglucosidase enzyme, also called myrosinase and give rise to products such as isothiocyanate, nitrite or thiocyanate (Josefsson, 1967; MacLeod, 1976) which are suggested to be involved in the olfactory signals and behavioural response to the host plant by the brassica insect pests (e.g. Whittakar and Feeny, 1971; see also Nielsen et al., 1979). The volatile isothiocyanate are responsible for the flavour and pungency of brassica vegetables (MacLeod & MacLeod, 1970; Sang et al., 1983; Sones et al., 1984). Such hydrolysis products exhibit a wide range of antifungal, antibacterial and insecticidal properties and also elicit physiological changes in man and higher animals (Lichtenstein et al., 1964; Fenwick et al., 1983; see also Sones et al., 1984).

### 2.1.1 Host plant characteristics

Cultivars of cabbage have been bred from plants indigenous to the coasts of England and Wales, the Channel Islands and West and Southern Europe (Henslow, 1908). Prior to their large scale cultivation as food, they were used mainly for medicinal purpose for ailments such as gout, diarrhoea, deafness and headache and as an antidote for poisonous mushroom (Yamaguchi, 1983).

#### 2.1.1.1 Growth and development

The cabbage seedling forms a red coloured hypocotyle, two notched cotyledons and a tap root system (Nieuwhof, 1969). There are two main phases of growth. The first period of growth "utilization" is given over to the

development of roots, leaves and stem while the later period "accumulation" is devoted to the development of the storage organ or large terminal bud called head. During the early period of growth cabbage plant develops a large number of green leaves and sometime later the young leaves form a compact mass which develops from the inside and contain no chlorophyll (e.g. Nieuwhof, 1969, see also Theunissen and Sins, 1984). Growing conditions, therefore, during the first period should be such as to favour the production of stem and leaves and in the later period they should favour the development of the storage organ and accumulation of carbohydrates (Edmond et al., 1964).

Studies on life history (Pearson, 1933) developmental pattern (Havis, 1940) and morphogenesis (North, 1957, 1960) have helped explain the growth and development of cabbage. Cabbage growth has been divided into recognizable stages such as pre cupping and cupping (Chalfant et al., 1979); pre heading or heading (Shelton et al., 1982); weeks after transplanting (Theunissen, 1984); seedling, transplanting, heading and harvesting stages (Strandberg, 1979) and first leaf stage, transplanting stage, harvesting stage, flowering stage and seed production stage for seed purposes (Theunissen and Sins, 1984).

Previously, Harcourt (1970) used growth stages of cabbage to design a crop life table in relation to pest damage. Similarly, Strandberg (1979) reported the quantitative description of fresh market cabbage growth and development in a winter production area of Florida State. He used phenological data and biomass accumulation

to produce growth curves related to calendar days and degree-days of the crop life cycle. Likewise, Strandberg and White (1979) projected the harvest dates of selected cabbage hybrids on the basis of 12 year cabbage growth and performance data but they failed to establish any relationship between cumulative degree-days or growth days to harvest and crop yield, head weight and percent heads harvested.

#### 2.1.1.2 Effect of environment on the vegetative growth

Investigations have shown that the optimum temperature for cabbage growth is between 15 °C and 20 °C and that above 25 °C growth ceases (Yamaguchi, 1983). Although there are some differences in the varietal response to temperature, the minimum temperature for growth is considered to be just above 0 °C (Iwama et al., 1953). Low temperatures are best withstood when the plants are half grown and the temperature drops gradually.

Light soils favour early crops whereas later crops thrive better on heavier soils because of higher retention of moisture (Nieuwhof, 1969). The water content of the soil at which cauliflower crops show optimal growth was estimated in percentage of the field capacity varies from 60-100 with an average of 80 depending upon the soil texture (Salter, 1960). Being a cool season crop the maturity period is 90-110 days (MacGillivray, 1953). The critical moisture-sensitive stage is from head formation to harvest (Chang, 1968) and the water requirement for

bringing a cabbage crop to maturity is 30 cm (Doneen and MacGillivray, 1943).

2.1.1.3 Plant surface

Varieties of B. oleracea are conspicuous due to the presence of a glaucous condition or waxy bloom. The dull, bluish-appearing bloom is the result of light scattering from deposits of epicuticular wax (Hall et al., 1965). It has been generally accepted that the primary purpose of cuticular waxes is to act as a water barrier between the plant tissues and the external environment (Hall and Jones, 1961; Daly, 1964). Purdy and Truter (1963 a, b, c) resolved cabbage leaf surface wax by thin layer chromatography (TLC) into nine fractions including long chain hydrocarbons, esters, ketones, primary and secondary alcohols and acids. The lipid fraction was examined also by Laseter et al. (1968) by combined gas-liquid chromatography (GLC) and mass spectrometry (MS). The surface of the non-glaucous brassica leaf differs considerably, physically and chemically, from that of glaucous leaves. The glossy brassica leaf is less waxy and less water repellent and its sparser wax contains less paraffins and ketones and a higher content of acidic substances than the wax from the waxy leaf (Martin and Juniper, 1970). These characteristics have been reported to have different effects on associated herbivores. Anstey and Moore (1954) demonstrated that a glossy-leaved mutant of sprouting broccoli, B. oleracea var. italica, was more susceptible to attack by the cabbage flea beetle,

Phyllotreta albionica, than the normal waxy one. On the contrary, Thompson (1963) noted that normal waxy plants in field population of marrow-stem kale, B. oleracea var. acephela, had larger colonies of the cabbage aphid whereas non-waxy plants in field were not colonised. Thompson (1963) concluded that the nature of the leaf surface is an important factor in the resistance of the plant to insects. Way and Murdie (1965) also reported that a non-glaucous strain of Brussel's sprout was more resistant to the cabbage aphid than the normal glaucous, but relatively more attractive to green peach aphid, Myzus persicae (Sulz). Leaf venation, branching and the texture of the wax layer were attributed to influence the movement pattern and searching behaviour of insects on plants (Fleschner, 1950; Banks, 1957; Shah, 1982).

## 2.2 Tasmanian Scene

### 2.2.1 Climate

Tasmania is an island of 67,897 sq km spanning latitudes 40-44°S. It has a temperate marine climate with mild winters and cool summers. The mean January temperature varies from 10 °C in the central highlands to 18 °C around the coast and in the midlands. The mean July temperature varies from 10 °C along the coast to 1 °C in the high lands (Langford, 1965). Annual evaporation is fairly uniform in the low level country of the central north-east and south-east, being between 78 and 86 cm. In the west and south-west the evaporation drops to less than 50 cm. Rainfall is distributed throughout the year but there are

relatively dry periods in late summer and late winter and relatively wet periods in late autumn and late spring (Langford, 1965). Tasmanian rainfall : evaporation ratio is <1.3 and the length of growing season over 9 months (Reid, 1981).

### 2.2.2 Brassica vegetable production

Tasmanian climatic conditions are particularly suitable for brassica vegetable production throughout the year. Mild winters allow the continuous harvesting of cabbage and allied crops. The harvested product is directed to the market and storage rarely occurs. Approximately 700 ha is devoted to brassica vegetable production (Aust. Bureau of statistics, 1983). Cabbages are grown by most market gardners. On the North-West coast the farmers have turned to other crops like Brussel´s sprout and cauliflower to meet the processing industry demands. The average economic value per annum brassica vegetables is given in Table 2.1.

### 2.2.3 History of cabbage pest control

Cabbage aphid, cabbage white butterfly and diamondback moth form the pest complex which attack cabbage and other brassica crops in Tasmania. Since the 1940´s these insects have been recognized as economic pests of cabbage (Evans, 1940). Cabbage aphid, termed as "Blight", was believed to have arrived in Tasmania in 1940 possibly in cargo but certainly from Victoria and widely established by 1942. Cabbage aphid was not as serious as caterpillars but in

Table 2.1 Brassica vegetable production in Tasmania (1981-82)[a].

| Crop | Area (ha) | Quantity of production | | Gross value of production | | Tasmanian proportion relative to Australian production (%) | No. of growers[b] | Average area per grower (ha) |
|---|---|---|---|---|---|---|---|---|
| | | Average per ha (tonnes) | Total (tonnes) | Average per tonne ($) | Total ($m) | | | |
| Brussels Sprouts | 138 | 20.3 | 2805 | 376 | 1.1 | 34.5 | 40 | 3.2 |
| Cabbage | 85 | 19.0 | 1616 | 194 | 0.3 | 1.7 | 52 | 1.8 |
| Cauliflower | 246 | 12.9 | 3184 | 281 | 0.9 | 2.4 | 86 | 2.4 |
| Swedes/Turnips | 228 | 12.2 | 2787 | 284 | 0.8 | 28.8 | * | * |
| Broccoli | * | * | * | * | * | * | * | * |
| Total | 697 | | 10392 | | 3.1 | | 178 | |

[a]Source: Australian Bureau of Statistics - 'Value of agricultural commodities produced during 1981-82 in Tasmania', dated 29 June 1983.

[b]Based upon production statistics (1978-79) compiled by the State Department of Agriculture, Hobart, Tasmania, in 1980-81.

*Statistics/information not available.

dry conditions it caused heavy infestations and its breeding continued on the cultivated plants or cruciferous weeds throughout the year (Miller, 1949).

The cabbage white butterfly was not recognized a pest till 1937 (Evans, 1937) and in 1943 cabbage growers suffered considerable losses due to this species. In 1942 a pteromalid pupal parasitoid, Pteromalus puparum (L.) was introduced into Tasmania from New Zealand and in 1945 a survey revealed that the parasitoid was abundant throughout the island (Miller, 1949). Since that time no additional reports on its biological effectiveness have been produced. Apanteles glomeratus (L.), a braconid parasitoid of butterfly larvae, was also introduced in 1949 and later it was found as established (Miller, 1949).

The diamondback or cabbage moth was a very common pest of brassica crops during the 1940´s. Although a proportion of the caterpillars of each generation was reported to be destroyed by the parasitoids they did not succeed in reducing the numbers of pests below desirable levels (Evans, 1940). In 1940´s non-insecticidal control measures involved the destruction of all old infested plants, the avoidance of planting seedlings near to areas previously infested and clean culture (Evans, 1940). An attempt was made to reduce insect damage by releasing two imported wasp parasitoids, Horogenes cerophaga (Grav.), a larval parasitoid, and Thyraeella collaris (Grav.), a pupal parasitoid, by the Entomology Division State Department of Agriculture reported in July, 1976 (Anon, 1976).

The history of insecticidal control of cabbage pests in Tasmania is presented in Table 2.2.

## 2.3 Life Systems of Cabbage Pests

### 2.3.1 Cabbage aphid

The cabbage aphid, (CA) is an economic pest of almost all cultivated brassicas in Australia. The sexual cycle of aphid has been suppressed because of mild winter in Australia (Hughes, 1963). The life cycle in temperate climate consists of oviposition by apterous oviparous females during the autumn. The eggs hatch in the spring to produce foundation female fundatrices which form colonies on their host plant (van Emden, 1966). Sometimes, green peach aphid (GPA) was also found to be feeding on senescing leaves of brassica plants but CA colonies were densely aggregated compared to GPA (Way, 1973). The dynamics and modelling of CA population have been studied by Hughes (1963) and Hughes and Gilbert (1968).

Many factors influence on aphid's growth and reproductive rate such as plant-water status (Kennedy, 1958; Wearing, 1972) which is believed to increase the total amino acid content of the leaves and phloem sap (Miles *et al.*, 1982), plant variety (Dunn and Kempton, 1969, 1971, 1972) growth regulators and herbicides (van Emden, 1964) and amino acids, soluble nitrogen and pottassium (van Emden 1966; van Emden and Bashford 1969, 1971; Miles *et al.*, 1982). White (1978) has suggested that outbreak of phytophagus insect pests might be relevant to their enhanced survival on the water stressed plants as a

Table 2.2 Chronological reports of chemical control of cabbage pests in Tasmania.

| Pest species | Year | Insecticide used/recommended | Remarks | Author |
|---|---|---|---|---|
| Brevicoryne brassicae (L.) | 1938 | Nicotine sulphate | Effective | Evans, 1938 |
| | 1949 | Nicotine sulphate | Effective | Miller, 1949 |
| | 1949 | DDT + BHC dust | Effective | Miller, 1949 |
| | 1975 | Demeton-s-methyl | Effective | Rapley, 1975 |
| | 1975 | Disulfoton granules | Effective | Rapley, 1975 |
| | 1981 | Carbaryl + rotenon chlorpyrifos, maldison, methidathion, phosphamidon, vamidothion | Unknown | Anon., 1981 |
| Artogeia rapae (L.) | 1940 | Lead arsenate 50% dust | Effective | Evans, 1940 |
| | 1949 | Lead arsenate + B.H.C.+DDT 1-2% | Effective | Miller, 1949 |
| | 1976 | Parathion-methyl 50% E.C. | Effective | Anon., 1976 |
| | 1981 | Acephate, azinphos-ethyl chlorpyrifos, endosulfon, fenval-erate, methidathion, methomyl, parathion-methyl, permethrin, trichlorfon | | |
| Plutella xylostella (L.) | 1940 | Lead arsenate or derris dust or spray | Effective | Evans, 1940 |
| | 1949 | B.H.C dust + 1-2% DDT | Effective | Miller, 1949 |
| | 1976 | Parathion-methyl 50 % E.C. | Effective | Anon., 1976 |
| | 1981 | Acephate, azinphos-ethyl, chlorpyrifos, endosulfon, fenval-erate, methidathion, methomyl, parathion-methyl, permethrin, trichlorfon. | Unknown | Anon., 1981 |

result of their increased amount of soluble nitrogenous compounds. Raworth et al. (1984) found that leaf water/dry weight was not a good predictor of developmental time, fecundity, adult weight, numbers and age distribution of CA. But with the increase in adult aphid weight the developmental time decreased and fecundity increased.

The cultural set up of an ecosystem plays a significant role in the survival of aphids. van Emden (1965) found that aphids were mostly attacked by syrphid larvae near flowers at the border edge of the field. Raworth (1984) correlated the first major decline in the rate of increase of CA with the appearance of a predatory cecidomyiid larvae Aphidoletes aphidimyza (Rond.). Natural enemies of CA include a braconid primary endoparasitoid, Diaeretiella rapae (McIntosh) whose efficiency was limited by high rates of hyperparasitism by Alloxysta brassicae (Chua, 1977), particularly towards the end of growing season (Hafez, 1961; Paetzold and Vater, 1966). Adverse climatic conditions caused considerable aphid decline (van Emden, 1963; Daiber, 1971). Other natural mortality factors involve infection by an entomogenous fungus (van Emden , 1963; Daiber, 1971) and predation by syrphid larvae (George, 1957; Hafez, 1961; van Emden, 1963; Way et al., 1969).

Aphids cause damage to brassica vegetables which involve serious losses in yield and quality and declines in plant's productivity by inducing virus diseases (Strickland, 1965). In Great Britain outbreak of cabbage aphid was recorded as early as 1929 (Barnes, 1931) and in

1957 the losses due to this pest in England and Wales were about £ 1 million per year on Brussel's sprouts alone (Strickland, 1957).

In Tasmania, especially in the North-West coast brassica vegetable area, the growers generally regard this aphid as the most important pest. Because of stringent demands by the processing industries and local markets for a pest free product the growers have no other choice than to spray the crops irrespective of the presence or absence of aphids.

### 2.3.2 Cabbage white butterfly

The cabbage white butterfly (CWB) is an economic pest of cultivated brassica crops. This species was reported in 1856 from Canada (Harcourt, 1961) across North America by 1883 (Peters, 1970) to Hawaii by 1898 and then to New Zealand and Melbourne by 1939 (Pescott, 1939). In 1943 it occured throughout Tasmania (Miller, 1949). The species attacks cultivated and voluntary plants of four families, namely Cruciferae, Resedaceae, Capparidaceae and Tropaeolaceae (Bonnemaison, 1965). Its biology and population dynamics have been studied by Muggeridge (1942), Harcourt (1966), Dempster (1967) and Common and Waterhouse (1972).

The butterfly lays eggs singly and usually at the underside of the leaves (Harcourt, 1963). The temperature threshold for oviposition was found to be approximately 10 °C and total egg production may range from 100-750 eggs per female (Gossard and Jones, 1977). Host selection and

perception of oviposition site have been intensively investigated as this species can discriminate strongly between the species of food plants (Feeny et al., 1983) and quality of the host plants (Radcliffe and Chapman, 1965; Ives, 1978; Wolfson, 1980; Myers, 1985). Nevertheless, the butterflies do not always prefer to oviposit on the species or variety of food plant on which their larvae survive and grow the best (Wiklund, 1975; Jones and Ives, 1979; Chew, 1980). Traynier (1984) has ascribed the role of "associative learning" to the ovipositional behaviour of the butterfly. The distribution of eggs on a particular host is also affected by the wind velocity (Harcourt, 1963), adult population density (Kobayashi, 1965) and plant density (Pimentel, 1961; Cromartie, 1975; Jones, 1977). Dempster (1967) indicated that the border plants in a plot received more eggs and especially on the underside of larger leaves. Variation in egg loads among plants can have important consequences for the future dynamics of insect populations (Monro, 1967). Harcourt (1962) proposed that for a moderate estimate of population, sampling of 20-70 plants would provide acceptable limits of precision. Gilbert (1984) has analysed the morphological and environmental parameters which could control the fecundity in this species.

Larval stage has 5 instars. The early instars make small round holes in the leaves whereas the later instar feed grossly on the leaf margin and lamina leaving the midrib or lateral veins of leaves. The first 4 instars have a developmental threshold of 10 °C, the fifth instars

approximately 9 °C and pupae 7 °C (Jones and Ives, 1979). The later instars can cause changes in both plant structure and the rate of plant growth (Samson and Geier, 1983). Pupation occurs after 5th instar usually away from the original host plant (Harcourt, 1961). Natural control agents in Australia involve larval parasitoids, A. glomeratus, A. rubecula and pupal parasitoid, P. puparum which were introduced from Canada, New Zealand and England respectively between 1941 and 1949 (Wilson, 1960). Since their initial establishment (Miller, 1949), these parasitoids have not suppressed the butterfly population below damaging levels (Hamilton, 1979). In contrast, Todd (1959) has shown the importance of P. puparum to parasitize CWB pupal population in New Zealand.

Birds have been reported as major predators of larvae and pupae of CWB (Baker, 1970). Currently the role of a predatory ant, Iridomyrmex spp. as a potential predator of CWB larvae is being investigated by Professor R. Jones in Australia (Jones, 1985). Virus disease epizootics in field populations of CWB larvae caused by a granulosis virus, Bergoldiavirus virulentum, were recorded by Wilson (1960) in Canberra, Teakle (1969) in Queensland, Hamilton (1979) in N.S.W., Todd (1959) in New Zealand and Harcourt and Cass (1968) and Jaques (1974) in Canada. Other factors inducing mortality are constant extreme temperatures causing larval death (Rahman, 1969) and egg cannibalism which occur at high larval densities (Jones and Ives, 1979).

### 2.3.3 Diamondback moth

The Diamondback moth (DM) is a cosmopolitan pest species of almost all cultivated and non cultivated crucifers and has been reported from different parts of the world having very different climatic conditions (Hardy, 1938; Robertson, 1939; Evans, 1940; Harcourt, 1960; Ooi and Sudderuddin, 1978; Nagarkatti and Jayanth, 1982). From the early days of its presence in N.S.W. Australia (Fuller, 1896) it has been a serious pest of crucifers almost all over S. Australia (Mr. Greg Baker, S. Aust. Dept. of Agriculture, Pers. comm., 1984). The moths are usually inactive during the day often hiding beneath the leaves but become active at dusk flitting from plant to plant and laying eggs (Miller, 1949).

The first generation of DM most commonly occurs on cruciferous weeds before moving to the cultivated crops (Ullyett, 1947; Harcourt, 1958, 1961). The cruciferous weeds which act as alternate host for this species (Kanervo, 1936; Ullyett, 1947; Harcourt, 1957, 1963) include Barbarea, Brassica, Capsella, Lepidium, Raphanus, Sinapsis, Sisymbrium and Thlaspi species. The relative abundance of these alternate host species seems significant for any population studies. Detailed population studies of DM have been conducted by Ullyett (1947), Oatman and Platner (1969), Weires and Chiang (1973) and Goodwin (1976). Except the studies by Harcourt and LeRoux (1967) and Goodwin (1976) other studies lack comprehensive measures of statistical significance in their data analysis.

Robertson (1939) has described the morphological characteristics of different stages of this species. The female usually mates once and lays about 160 eggs, singly or in small groups, on the leaves of the food plant, mainly on the upper surface (Beirne, 1971) along the midrib (Harcourt, 1963). Oviposition is restricted in those months with an average mean temperature below 9 °C (Goodwin, 1976). Considerable mortality results from the failure of gravid females to lay their full complement of eggs. Moreover, the moths rarely fly during cool or windy weather and any prolonged period of "inclement conditions" during the adult stage reduces activity resulting in the death of many females before oviposition is completed (Harcourt, 1963). Reid and Bare (1952) found maximum activity of this pest during early spring to early summer (88-100 larvae per plant) and that activity was limited in mid-summer by high temperature. Dhaliwal and Goma (1979) reported that average maximum temperatures ranging from 18-27.5 °C and relative humidity of 36-56% favoured its multiplication.

There are 4 larval instars (Harcourt, 1963). Larvae feed on surface tissues of the leaves and usually mine between the leaf surfaces and make "windows". Most injury is done during the final instar and in addition to feeding on the leaves the larvae may attack the marketable portion of the plant (Harcourt, 1963). The duration of larval feeding is 12-24 days before pupation which lasts from early spring to early winter in Tasmania (Miller, 1949). The larva spins a net like cocoon and pupates inside it.

The adult emerges after 1-2 weeks. The life cycle may be as short as 16 days with a variable number of generations per year (Hely et al., 1982). The developmental threshold temperature is less than 5 °C and effective time-temperature value from egg to adult stage was 225 degree-days based upon a theoretical threshold temperature of 9.8 °C (Bonnemaison, 1965). Environmental limits for successful overwintering have been given by Harcourt (1957) and Smith and Sears (1982) in Canada and by Umeya and Yamada (1973) in Japan. Its distribution throughout regions of diverse climatic conditions and its adaptability and survival in this range has been partly ascribed to its rapid growth response to temperature and dispersal capability over very long distances (Harcourt et al., 1955, 1956; Shaw, 1959; French and White, 1960; Stepanova, 1962; French, 1966; Johnson, 1969; Umeya and Yamada, 1973). Peak flights occur at 2-4 h after sunset (Goodwin and Danthanarayana, 1984). No studies on the population dynamics and ecology of this species has been conducted in Tasmania.

Regulation of natural populations was attributed to cool and cloudy weather and heavy showers accompanied by thunderstorm causing 74% reduction in larval populations (Harcourt and LeRoux, 1967; Beirne, 1971), disease (Ullyett, 1947; Harcourt and LeRoux, 1967) and parasitism (Hardy, 1938; Todd, 1959; Oatman and Platner, 1969; Putnam, 1973). However, Goodwin (1976) concluded that the existing parasitoids, predators, disease and weather normally failed to exert any suppression on the population

of this pest in Victoria. Putnam (1973) suggested that the level of parasitism in the first larval generation of the host was of major importance because of its ultimate effect on the numbers of the potentially injurious, second larval generation. The synchronization of the parasitoid's activities especially against the first spring generation of DM was of vital importance in Canberra (Dr. D.F. Waterhouse, CSIRO Canberra, Pers. comm., 1984). Other studies have documented that level of parasitism may be insufficient to control the pest population (Harcourt, 1960; Pimentel, 1961; Oatman and Platner, 1969; Yarrow, 1970) and the existence of these biotic mortality factors did not sufficiently affect the DM population.

## 2.4 Host-Plant Selection

Host-plant selection is a process involving a number of successive neural and metabolic steps which ultimately result in the insect's feeding or ovipositing on the plant (Brues, 1920; Thorsteinson, 1960; Dethier, 1982). Each step consists of a behavioural response to specific stimuli : if the insect perceives the stimuli to be correct then it moves on to the next step but if the appropriate stimuli is absent then the behavioural response is terminated (Hodkinson & Hughes, 1982).

The first response to a variety of stimuli is a dispersal flight (Johnson, 1969). An insect is attracted either by olfactory cues (Wallbank and Wheatley, 1979; Finch and Skinner, 1982) or to visual stimulus (Vaidya, 1969) or perhaps both (Harris and Miller, 1982). The

chemical cues, emenated from the plant are perceived either at a distance from the host or after arrival on the host (Kennedy, 1977).

It has been suggested that sinigrin (mustard oil glucoside) is a specific stimulus for host selection by CA (Wensler, 1962) which is received via the stylet after it is penetrated the leaf surface (Nault and Styer, 1972). Moon (1967) proposed that sinigrin increased settling behaviour of CA on solutions but not ingestion. Some workers regarded these glucosides to be responsible for host-plant selection by the larvae of P. brassicae (Verschafelt, 1911), CWB (Verschafelt, 1911; Hovanitz et al., 1963) and DM (Thorsteinson, 1953, 1960). Nayer and Thornsteinson (1963) have demonstrated that a whole range of glucosides stimulate differentiated effect on the feeding of DM larvae. Traynier (1967) suggested that the odour from cabbage plants stimulated activity of the cabbage root fly, Delia brassicae, which led to oviposition. However, the field experiments by Hawkes (1974, 1975) did not support this hypothesis as the gravid female flies released downwind of a host crop moved towards it. On the contrary, Coaker and Smith (1970) demonstrated that female flies flew upwind in the presence of host plant odour in a small wind tunnel. According to Hawkes and Coaker (1979) these conflicting findings appear to be consistent with more general difficulties of observing behavioural response to host plants. In this context many laboratory experiments have often been misinterpreted (see also Kennedy, 1965).

Traynier (1979) has noted that excitation by tarsal contact with cabbage resulted in an increased tendency of gravid CWB females to land on non-host plants and that vision alone could suffice for host location. More recently Renwick and Radke (1983) have argued that the mechanism by which CWB gravid females discriminate would need more than one non-volatile chemical for both stimulation of oviposition and selection of the exact oviposition site. They concluded that this mechanism is still unknown and that further studies are needed for a full understanding of the underlying phenomena. This knowledge may provide a basis for further developments of present methods of pest suppression and the starting point for new innovative methods.

## 2.5 Insect Herbivory and Plant Response

An insect herbivore must overcome many barriers to feed on its host plant. These barriers are related to ecological requirements, geographical distribution, temporal availability and microclimatic and physical properties of the plant's habitat (Tahvanainen, 1983). A variety of interactions are involved between herbivores and their host plants. Some of these interactions involve mortality of either whole plant (Cushing, 1964) or plant reproductive structures (Shaw, 1968) or a large decrease in quality without decreasing yield (Ordish and Toft, 1965). Metcalf and Flint (1962) summarized various types of injuries to host plants. McNaughton (1983) outlined three contrasting opinions regarding the effect of

herbivory on the fitness of affected plants. First, the most widely accepted belief that herbivory is always detrimental to the plant attacked; second, plants can compensate for low levels of herbivory; and third, a minority opinion, that moderate levels of herbivory may result in overcompensation.

Interpretation of vegetative losses into proportional reduction in the final yield (vegetative or reproductive) is dependent upon the species of plants attacked and the nature of herbivory (e.g. Taylor and Bardner, 1968; Bardner and Fletcher, 1974; Jackson, 1980). Usually the effect of defoliation depends upon the specific growth or developmental stage of host plant. Hare (1980) reported that, despite an almost 100% defoliation of potato plants by Colorado potato beetle, Leptinotarsa decemlineata, the tuber yield was unaffected except when defoliation occured between the fourth and sixth week of growth. de Wilde (1982) proposed a hypothesis which explained some of the complexities involved in a plant's susceptibility, tolerance or resistance to insect damage namely:

a. an insect species is as such never a pest, but some individuals of its population may be,
b. the pest status of an insect depends on ;
    (i) the choice of its host plant and
    (ii) the building up of numbers above a certain critical threshold of tolerance resulting in economic losses.
c. agronomic activities of man often result in the creation of pest problems.

The significance of a pest is usually determined by the intensity (Conway, 1976), the duration (Hughes, 1963) and the frequency (Harcourt, 1963) of attacks. These factors should always be determined in conjunction with the phenological stage of host plants. Caviness and Thomas (1980) reported that during the vegetative growth of soybean, Glycine max (L.), defoliation has less effect on seed yield than during the seed filling stage. Such compensatory responses have also been reported in French bean, Phaseolus vulgaris (L.) by Binnie and Clifford (1968). Partial defoliation resulted in an increase in light saturated photosynthesis in remaining intact leaves (Delting et al., 1979) and this was associated with sudden increases in carboxylating enzymes in both C3 and C4 plants (Waering et al., 1968).

Another internal process, which promoted plant growth, was high cytokinin levels (Pozsar, 1980) while external processes include improved microclimate for remaining tissues through increased nutrient supplies (Chew, 1974; Batzli, 1978), enhanced water status of remaining tissues i.e. increased root-shoot ratio (McNaughton et al., 1983), direct transfer of growth regulators from the herbivore to the attacked plant (Dyer, 1980) or through saliva transfer during feeding (Miles, 1968; Dyer, 1980). This usual occurrence of compensation has been depicted by Tammes (1961) in his pest-yield relationship sigmoid curve (Fig. 2.1).

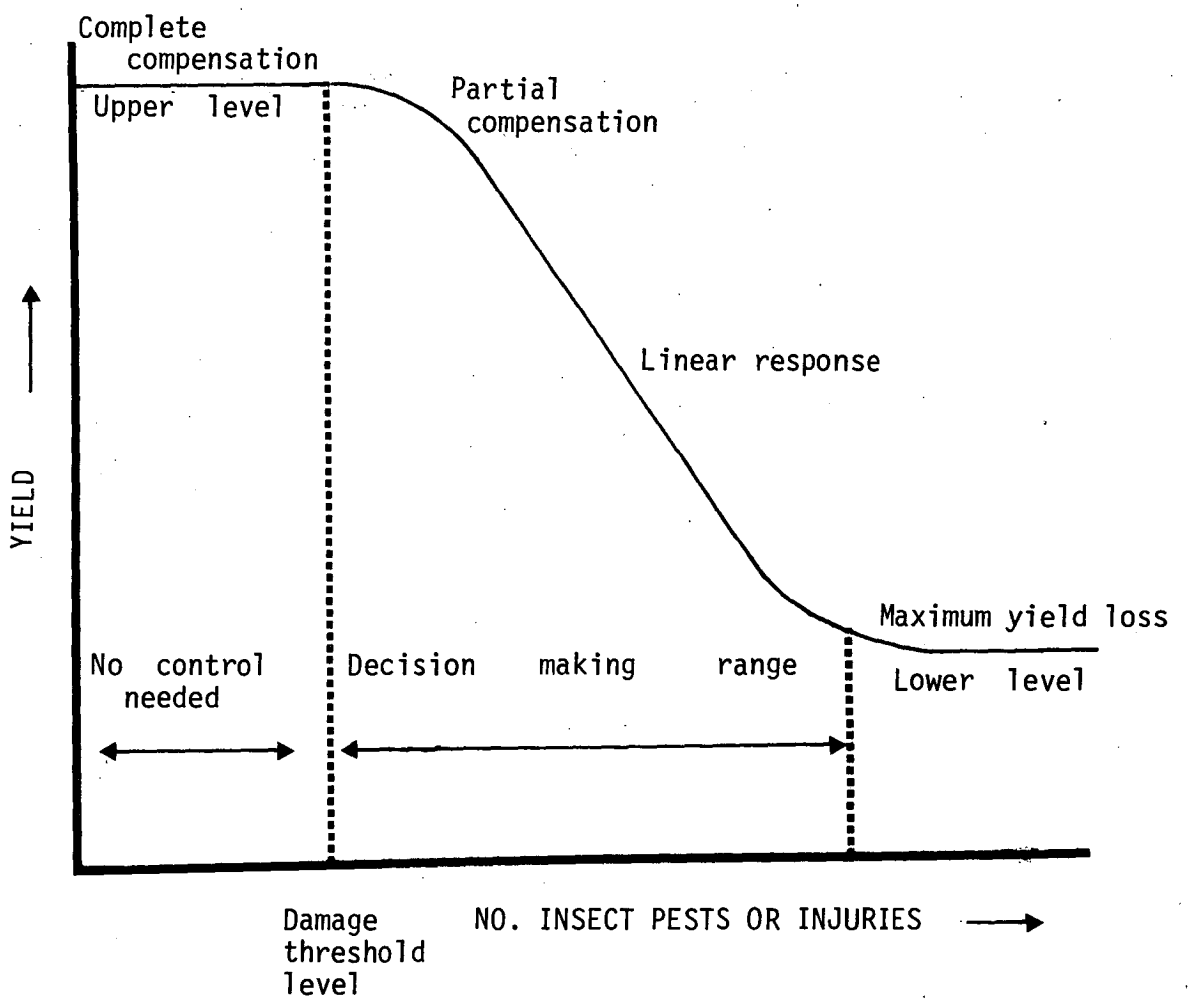


Fig. 2.1. The generalised pest-yield relationship (after Tammes, 1961).

Dramatic changes may occur in the plant's chemistry after the herbivory or simulated damage (Ryan, 1978; Wallace et al., 1984). The ability of an insect to feed on a plant may also be seriously affected by the history of prior insect feeding (e.g. Liljegren, 1984). This induced "immune response" has been demonstrated in cotton seedlings where mite populations grew more rapidly on new growth of unattacked seedlings than on the new growth of previously attacked plants (Karban and Carey, 1984). Such intimate physiological relationship of a herbivore with its host plant is a key factor in interaction studies.

The capability of CA to cause changes in its host plant metabolism similar to those which occur when a plant approaches senescence was shown by Dixon (1976). These changes have been explained by Way and Cammell (1970) to be to the aphid's advantage possibly through improved nutrition by proteolytic production of free amino acids (van Emden and Bashford, 1971). On the other hand, aphid infestations cause a drop in turgor pressure (Wearing and van Emden, 1967) and severe wilting (van Emden et al., 1969; Forrest et al., 1973).

This wilting was attributed to reduced root growth (van Emden, 1969), increased inhibitor and decreased growth promotor levels (Hussain et al., 1973). On the contrary, a marked increase in moisture content of aphid infested plants was assigned to toxic metabolites from plant or insect in response to the stimulus by the insect

(van Emden, 1973). Way and Cammell (1970) showed that CA feeding on Brussel´s sprout leaves increased the rate of nutrient-flow into the infested leaves and decreased the flow into growing tissues.

The DM larvae preferred to feed on the young leaves of turnip and stimulated the plant to retain older leaves causing an increase in the total dry matter content of the plant (Taylor and Bardner, 1968). Jackson (1980) determined the effects of artificial defoliation at different growth stages of radish. He found that hypocotyl yields were negative linear functions of the level of defoliation irrespective of growth stage. The plants were found to be unable to compensate for loss of foliage and yield was proportional to leaf area duration whereas the maximum losses in yield followed the earliest defoliation.

The actual site of defoliation is a critical factor determining the plant response (Taylor and Bardner, 1968). Differences between the effects on yield of various combinations of plant-insect were shown to be caused by variations in the amount of leaf eaten and the distribution of injuries between the leaves affecting the production of dry matter (Capinera and Roltsch, 1980).

## 2.6 Estimation of Crop Losses

### 2.6.1 Rationale

Crop losses due to insect herbivory can be assessed by:

(i) estimating the loss experienced at varying

natural population levels (Judenko, 1972),

(ii) inducing measurable loss by a controlled herbivore population (Hare, 1980) or

(iii) through simulating the damage by artificial means (Jackson, 1980).

The quantitative relationship between the intensity of pest infestation and its effect on yield usually corresponds to a part of a generalised response curve described by Tammes (1961) but complications occur when quality is important in assessing yield. Quality and yield loss are not always related in the same way to the infestation (e.g. Brazzel and Gaines, 1957). Moreover, the relationship between infestation and yield is influenced by variation in the conditions for plant growth, time of attack and site of infestation (Wilson et al., 1969). James (1974) outlined serious problems with measuring and projecting yield losses in field crops because a pest damaged crop usually produces some yield and as the maximum yield is unknown, it is very difficult to estimate the yield losses. Simulation of insect damage has been criticized as insect feeding takes place over a time rarely occuring on a single day (Poston and Pedigo, 1976). Another problem occurs if crop loss assessments are done when two or more different pests occur simultaneously on the same crop. According to Le Clerg (1971) in this situation estimates of losses based upon the assumption of independence of action are unreliable and a fully objective assessment of losses requires the estimation of all possible interactions between pests and crop to

apportion the contribution of each pest to total loss.

### 2.6.2 Quantification of cabbage losses due to insect pests

Specialized sampling techniques with a comprehensive precision have been developed for estimating insect pests population and damage assessment (e.g. Reid, 1940; Prasad, 1963; Shepard, 1973). Both quantitative and qualitative losses jeopardize the marketability of cabbage crop (Prasad, 1963). Plants, during seedling stage suffered severe losses by flee beetles in Europe affecting crop establishment which was a critical factor in the success of the crop (e.g. Jones and Jones, 1974). Samson and Geier (1983) concluded that the growth rate of cabbage plants depended mainly on their photosynthesizing area which was additive during early development but remained constant later. Baker (1984) derived an action threshold for DM larvae affecting yield and quality of cabbage. He concluded that the :

" . destruction of apical buds of seedlings gave rise to either no head or multiple undersized heads ;

. reduction in quality of harvested cabbages because of the presence of perforated foliage on marketable unit ;

. loss in photosynthetic area resulted into reduction of weight in average harvested heads".

Reduction in growth rates has been reported by

Nieuwhof (1969) because of aphid colonies which, apart from removing of assimilates, transmitted turnip yellow mosaic virus. The quality of the crop i.e. marketable portion is also diminished by the aphid attack, contamination by honeydew production and subsequent fungal growth (Nieuwhof, 1969).

## 2.7 Dynamics of Pest Population

### 2.7.1 General

Population dynamics and population interactions are the most important mechanisms which contribute to the understanding of the functioning of herbivorous insect communities. There are three basic questions in population dynamics namely :

- why populations fluctuate ,
- how populations fluctuate ,
- how populations are regulated

(Strong et al., 1984).

It is a generally accepted principle that populations are regulated or controlled by density dependent processes and disturbed by density independent processes (Strong et al., 1984). The impetus to understand this scenario of cyclic abundance urged many workers to conduct studies on the ecology and population dynamics of various insect species (e.g. Andrewartha and Birch, 1954; Hughes, 1963; Morris, 1963; Varley and Gradwell, 1970; Huffakar et al., 1971; Berryman,1973; Baltensweiler et al., 1977; Wolda, 1978; Southwood et al., 1982; Raworth et al., 1984). Mostly, the populations were found to be influenced by the

regulatory factors i.e. mortality factors, without which the populations are believed to either increase to infinity or decrease to extinction (e.g. Nicholson, 1933; Smith, 1935; Huffakar et al., 1971). Johnson (1969) and Wellington (1980) emphasized the role of dispersal behaviour in the dynamics and growth of an insect population. General accounts of population dynamics have been given by Clark et al. (1967) and Varley et al. (1973).

### 2.7.2 On cabbage

The biology and population dynamics of CA, CWB and DM have been extensively studied in different parts of the world (e.g. Reid and Bare, 1952; Harcourt et al., 1955; Hafez, 1961; Harcourt, 1966; Lamb and Lowe, 1967; Dempster, 1968; Oatman and Platner, 1969; Goodwin, 1976; Chua, 1977; Dhaliwal and Goma, 1979; Hamilton, 1979; Ru and Workman, 1979; Andaloro et al., 1982; Jackson, 1982; Nagarkatti and Jayanth, 1982; Raworth, 1984; Raworth et al., 1984 a,b). No systematic records on intensity, timing, frequency and population fluctuation of these pests are available in Tasmania.

Considerable variations in population peaks of insect pests may occur between different sites and seasons (Strickland, 1954). Population maxima of CWB was observed in autumn (Dempster, 1968; Parker, 1970) where as Hamilton (1979) recorded peaks in both spring and autumn. The timing of peak activity of DM also varied between different years (Hamilton, 1979). Differences were also

found between CWB populations from Australia and Canada for their behaviour (Jones, 1977) and reproductive timing (Jones et al., 1982).

Various factors have been associated to changes in population and cyclic abundance of cabbage pests. Among abiotic factors, temperature has been found to greatly influence the population status, morph formation and developmental rate of these pests (Hughes, 1963; Lamb and White, 1966; Butts and McEwen, 1981; Jones et al., 1982; Gilbert, 1984). Rainfall and high relative humidity has been attributed as detrimental to CA population (Strickland, 1957; Broadbent and Heathcote, 1961). Moreover, during cool and wet conditions severe epizootics of entomogenous fungi were responsible for marked decline in aphid population (Hughes, 1963; Dunn and Kempton, 1971 b). Similar conditions also assisted the spread of the virus disease in CWB (Harcourt, 1966; Hamilton, 1979). Beirne (1971) reported on the dislodging effect of rainfall against DM populations from their host plants. Severe drought condition causing wilting of host plant drastically reduced the CA survival and rate of reproduction (Wearing, 1972). However, high temperature and high level of humidity were not attributed to a marked decline in population density of DM (Yamada and Kawasaki, 1983).

High wind velocities were found to affect the flight pattern (Kring, 1972), settling rate (Fidler, 1949) and shelter seeking (van Emden, 1965) of CA and the dispersal direction of DM moths (French, 1966; Shaw and Hurst, 1967;

Lokki et al., 1978). Photoperiod has been reported to affect the nymph production in aphids (Kawada, 1967) and flight activities in DM (Harcourt, 1963; Goodwin, 1976) and CWB (Ives, 1978).

## 2.8 Population Sampling

Sampling is undertaken to gather information on attributes such as distribution, abundance, crop-pest interactions, crop loss assessments and efficacy of natural or applied control measures. The objectives of an investigation generally govern the sampling technique, however, Yates (1981) pointed out that an efficient and optimal sampling method involves minimizing cost of work in relation to the accuracy required.

Morris (1960) emphasized the importance of selecting appropriate confidence limits of sampling techniques. Knowledge of the spatial and temporal distribution pattern of an insect can be used in the design of a sampling method with appropriate sample size and intervals (Harcourt, 1961).

Rapid yet precise sampling methods in cabbage crops have been used in the past, including direct in situ counting (Strickland, 1957), counting on the whole plant (Shelton, 1983; Trumble et al., 1983), a 4-quadrat division method (Harcourt, 1961) and head plus 10 surrounding leaves (Sears et al., 1985) taken as an individual sampling unit. However, Sears et al. (1985) concluded that, due to variation in the environmental conditions, rapid larval movement into the cabbage heads

was a problem in precise assessment.

Sequential sampling methods have been developed for CWB larvae (Harcourt, 1966) and CA (Wilson et al., 1983). Shepard (1973) noted that this method provides rapid classification of population levels with a minimum number of samples chosen randomly or systematically with an acceptable confidence level. In contrast, Hoy et al. (1983) considered that a sequential sampling plan lacks the extensive survey of the entire sampling area and since sampling is abandoned when the population density is classified, above or below a critical level, this could possibly affect the accuracy of a treatment decision.

Populations of CA have been counted directly on plants (Dunn and Kempton, 1971 a), on a per plant basis (Hafez, 1961; Hughes, 1963) or on leaf sub samples (van Emden, 1965). Due to marked variability in the distribution of CA on cabbage plants (e.g. Otake, 1957) sampling of whole plants as fixed sampling units can give accurate estimates of population densities, distribution and inter or intra plant variation.

The choice of sample size is a crucial factor for accurate population assessments especially in a multi pest situation where intra-specific competition may affect local population densities (Way and Cammell 1970; Dixon and Wratten, 1971). Harcourt (1961) recommended that 150, 50, 50, 40 and 40 plants should be sampled for DM eggs, larval instars I to III, and pupae. Trumble (1982) concluded that a 10-plant sampling unit reduced variations in aphid counts on broccoli plants when

population exceeded a log ( $\bar{X}$ + 1) value of 0.65 and suggested that at higher population levels fewer samples per ha would be needed for reasonable statistical accuracy.

## 2.9 Host Plant Resistance

Plant resistance to insect pests is a heritable characteristic whose mechanism and magnitude can be determined by studying the mutual interactions between the plant and insect e.g. behavioural and metabolic (physiological) responses of insect to the host plant and the growth and development of the plant in response to insect feeding and reproduction (Tingey, 1981). Painter (1951, 1966) regarded resistance as a relative term associated with interaction between a herbivore and a plant host and categorized it into 3 operational basis :

1. Preference or non preference
2. Antibiosis
3. Tolerance

Beck (1974) redefined resistance as :

> "collective heritable characteristics by which a plant species, race, clone or individual may reduce the probability of successful utilization of that plant as a host by an insect species, race, biotype or individual."

He did not include tolerance in his explanation of resistance for he regarded it as a different type of

biological relationship.

The future of host plant resistance and development of resistant cultivars is very bright (see Brett and Sullivan, 1974; De Ponti, 1979) especially in temperate agriculture where it can interact beneficially with both chemical and natural control agents. Moreover, in low value per unit area crops, conventional methods of insect control may be too costly to justify persistent seasonal control because of low profit margin (Painter, 1968). Pathak (1970) amply explained the future prospects of using resistant host plants in pest population suppression strategies.

> "The unique advantages of resistant varieties are that, irrespective of the level of resistance, they reduce insect numbers at all levels of infestations, are cumulative in their effect and are compatible with other methods of insect control. In addition, they do not require additional expenses to the farmer and cause no toxicity or environmental pollution hazards."

Headly (1979) projected the role of inherent host plant resistance and emphasized that the knowledge of the host plant interaction and mechanism of resistance would help both the research entomologist and the grower to utilize the net results of the assessment as a clear and steadfast rule.

Mechanism of resistance in plants is a complex phenomenon. Its bases are usually categorized as host plant characteristics such as plant chemical profile (Fraenkel, 1959, 1969; Schoonhoven, 1969); phytochemical stimuli (Whittakar and Feeny, 1971); morphological characteristics (Maxwell, 1972) and nutritional

composition (House, 1969; Beck and Reese, 1976).

Accounts of resistance in crucifers have been made by Radcliffe and Chapman (1965, 1966); Rudder and Brett (1967); Creighton et al. (1975); Dickson and Eckenrode (1980) and Lin et al., 1983. Unfortunately resistance is not a universal panacea to all insect pests as Radcliffe and Chapman (1966) noted that the relative resistance of cabbage cultivars to a specific herbivore was independent of the level of resistance to other cruciferous insect herbivores.

Host non-preference can affect the settling of immigrants and their reproductive rate can be suppressed due to unfavourable characteristics of the host plant (Dunn and Kempton, 1969). Sometimes the initial preference by incoming herbivores (alate aphids, gravid females) is not always related with the ultimate degree of damage or limitation in the growth or reproductive rate of herbivores, suggesting evidence of antibiosis (Dunn and Kempton, 1971 a; Lin et al., 1984).

Lin et al. (1983) found that DM females preferred cabbage cultivars with dark green foliage for oviposition but later on Lin et al. (1984) observed that after egg hatching DM larvae failed to develop on those dark green glossy foliage of the inbred cabbage lines. Dunn and Kempton (1976) concluded that red foliage cultivars of Brussel's sprout were much less attacked by CWB than green foliage cultivars. Radcliffe and Chapman (1966) regarded non-preference as the primary mechanism of resistance of cabbage varieties to CWB and cabbage looper, Trichoplusia

ni (L.), and that due to "colour or colour-related factors" red cabbage varieties were less preferred by CWB for oviposition although these varieties favoured establishment and survival of CWB larvae and increase in CA densities. Cabbage plant structure has also been found to affect the establishment of CA and other cruciferous pests (Dunn and Kempton, 1971 b).

Waxy cultivars have been shown to lack resistance to cruciferous pests. Way and Murdie (1965) demonstrated that non-waxy cultivars of Brussel's sprouts were resistant to CA and cabbage moth, Mamestra brassicae (L.), but were not resistant to M. persicae and E. brassicae. In contrast, Ellis et al. (1984) observed that glossy foliage cabbages were severely damaged by flea beetles, P. brassicae. Other accounts of association of non-waxy cultivars with the resistant characteristics have been made by Thompson (1963) on marrow-stem kale to CA. Interestingly, Cole and Rollason (1984) found that the cuticle of the resistant cabbage to aphid and lepidopterous larvae had about half the wax found on susceptible plants.

Syrphid predators preferred glossy varieties of Brussel's sprouts and a greater ratio of the number of syrphid eggs to CA was found on the glossy than on waxy varities (Way and Murdie, 1965). This may contribute to an apparent resistance of glossy varities to CA.

Plant substances or inherent antagonistic nutrient factors (e.g. van Emden and Way, 1972) have been often mentioned to affect the behavioural responses of associated herbivores. Nault and Styer (1972) regarded

sinigrin as a stimulating factor for settling of CA. Proline (pipecolic acid) has been reported to increase resistance to CA and to T. ni larval feeding and oviposition (Benepal and Hall, 1967).

## 2.10 Chemical Control of Cabbage Insect Pests

Chemical insecticides belonging to organochlorine, organophosphate, carbamate and pyrethroid groups provide the means of controlling approximately 90% of current insect pest problems (see Knipling, 1979). This trend will continue into the foreseeable future because in the current climate of ever-increasing demand for food and fibre, the development of equally effective, dependable and economic alternatives seems difficult. Nevertheless, the wide spread recognition of unforseen problems originating from pesticidal over-use (e.g. Watson and Brown, 1977), demands a greater understanding of the nature and use of chemicals and their integration with non-chemical techniques of pest suppression (see also Brader, 1976, 1982).

Insecticides generally serve two purposes :

(i) to protect the economic or marketable portion of the crop from insect damage,

(ii) to protect the whole plant from insect damage under optimum growth and development conditions to obtain maximum yield.

Insecticidal application with standard spray techniques, is often inefficient (Pimentel et al., 1978).

In these circumstances the decision making process relating to time, place and method of application of an insecticide is of prime importance in any pest control strategy (Norton, 1976; Norton and Conway, 1977). Mayer (1959) has suggested 3 ways to enhance the efficacy of insecticide and to prevent the development of resistance:

a. avoiding frequent treatments with the same insecticides,
b. using chemicals with different modes of action and
c. changing the control measure frequently.

Norton (1976) identified four factors which help determine a pest control decision against a pest problem:

a. the grower's objective;
b. his perception of pest attack and damage it causes;
c. the control measures available to him and
d. the decision making process (see also Fig. 2.2).

The fate of pesticidal residues and their persistence in edible portion of the plant is another major concern, especially in short duration crops (see Bondarenko, 1982). This problem can be overcome by following the manufacturer's recommendations for safe and effective use of pesticide with no risk to consumers (Martin, 1960).

Kovachich (1973) stressed the need to standardise pesticidal chemicals in order to avoid any confusion in the selection of suitable products for a particular job

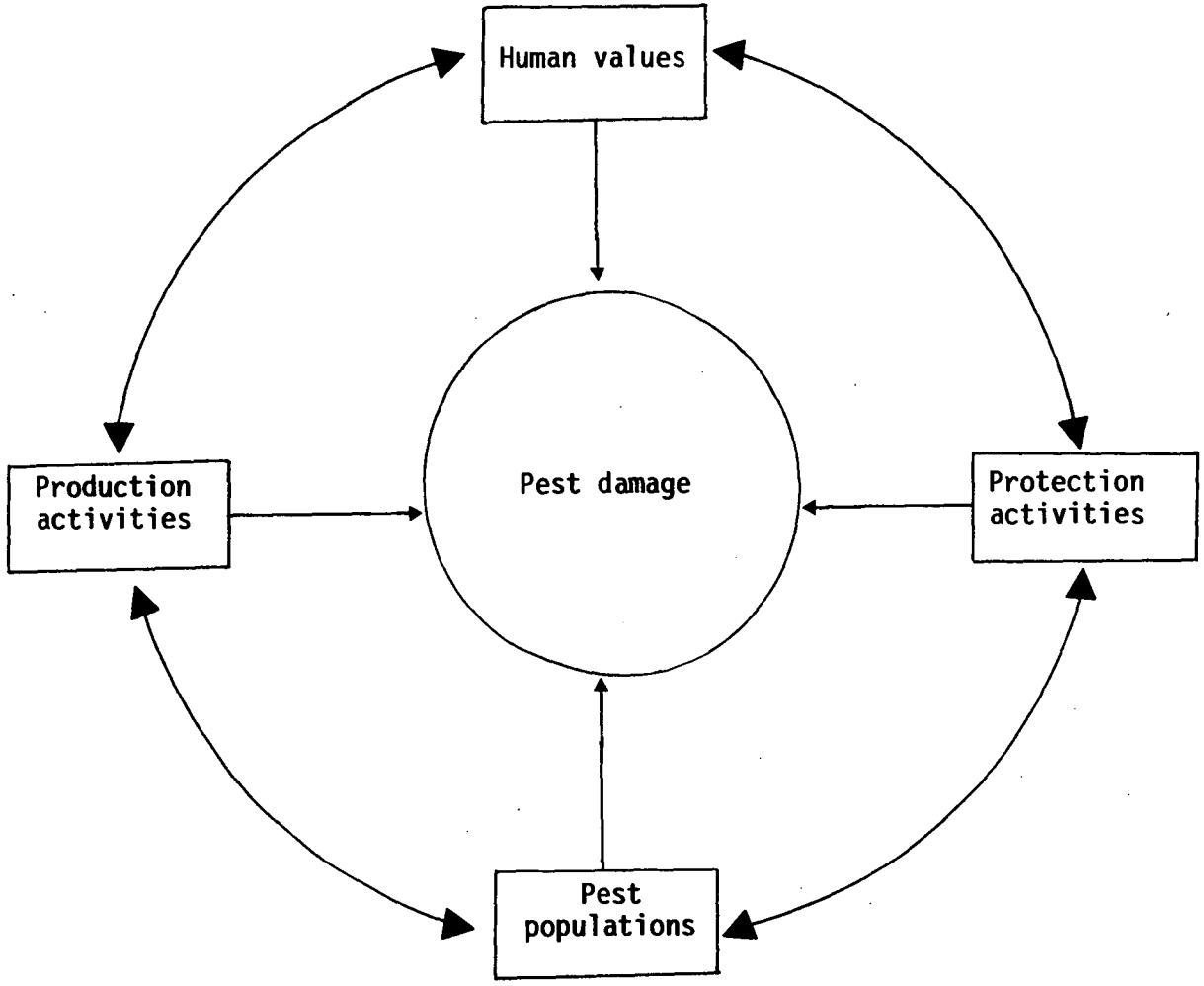


Fig. 2.2. The socio-economic context of a pest problem as characterized by Norton and Conway (1976).

thereby reducing hazards involved in the preparation and application of insecticidal formulation (e.g. Mellanby, 1967).

Synthetic chemical insecticides are the main tools for insect pest suppression in brassica vegetable production systems all over the world. Preventive insecticidal treatments, usually in the form of insurance sprays, are applied to combat the recurrent pest problem in order to satisfy the consumer's demands for high quality, blemish free vegetables (Norton and Conway, 1977; Sly, 1978). Dunn and Coaker (1965) noted the problem of broad spectrum chemicals, with long persistence in inappropriate formulation and applied in a broadcast pattern, are aversive approaches to rational control of pest situation in vegetable crops.

Apart from formulation of insecticides and regardless of their use the performance of an insecticide is greatly influenced by the appropriate number and size of sprayer nozzles, spray pressure, concentration of pesticide, driving speed , plant size and shape, foliage density spacing, insect habitat and timing (Chiba, 1973).

The following review (Table 2.3) contains citations of research on the use of chemical insecticides against cruciferous insect pests which substantiates the principle that future strategies will embark on reducing or making the pesticidal use more effective.

Table 2.3 Summary of the literature concerning the use of chemical insecticides against cabbage pests on cabbage or other brassica crops (1960-86).

| Chemical | Pest | Crop | Criteria of application | Country | Comment | Author(s) |
|---|---|---|---|---|---|---|
| Thiometon<br>Fenthion<br>Demeton-s-methyl<br>Dimethoate<br>Megatox | *B. brassicae* | Choumoellier | Population density | N.Z. | Significant control ($P = 0.01$) | Lowe, 1960 |
| DDT | *P. rapae* | Brussel's sprouts | Population peak, twice a year | U.K. | Short lived control | Dempster, 1968 |
| Parathion<br>Toxaphene | *T. ni* | Cabbage | Economic threshold | U.S.A. | Effective | Greene, 1972 |
| Malathion<br>Parathion<br>Mevinphos<br>Naled<br>Dichlorovos<br>Dimethoate<br>Phosvel<br>Carbofuron | *P. xylostella*<br>*Plusia orichelsea*<br>*M. persicae*<br>*Lipaphis erysimi*<br>*B. brassicae*<br>*Crocidolomia binotalis*<br>*Bagrada cruciferarum* | Cabbage | Fixed schedule | India | Effective | Govinden, 1972 |

Table 2.3 (continued)

| Chemical | Pest | Crop | Criteria of application | Country | Comment | Author(s) |
|---|---|---|---|---|---|---|
| Parathion<br>Toxaphene | *T. ni* | Cabbage | Population density | U.S.A. | Effective | Shepard, 1973 |
| Mevinphos<br>Diazinon<br>Tetrachlorvinphos<br>Methidathion<br>Trichlorphon<br>Mevinphos | *P. xylostella*<br>*P. rapae*<br>*Hellula hydralis*<br>*Crocidolomia binotalis* | Cabbage | Fixed schedule (14-days) | Aust. (Qld.) | Effective | Smith, 1975 |
| Monocrotophos<br>Dimethoate<br>Bromophos<br>Phosphamidon<br>Aldicarb<br>Methomyl | *B. brassicae* | Cauliflower leaves bioassay | Critical doses for toxicity index | Egypt | Most effective to least effective:<br>Aldicarb<br>Phosphamidon<br>Dimethoate<br>Bromophos<br>Monocrotophos<br>Methomyl | Mesbah et al., 1978-79 |
| Acephate<br>Methamidophos<br>Bendiocarb<br>Diflubenzuron | *P. xylostella* | Cabbage | Leaf damage (severity index) | Malaysia | Significant reduction in field population | Mohammad et al., 1979 |

Table 2.3 (continued)

| Chemical | Pest | Crop | Criteria of application | Country | Comment | Author(s) |
|---|---|---|---|---|---|---|
| Leptophos<br>Methamidophos<br>Methomyl<br>Permethrin | P. xylostella<br>A. rapae<br>T. ni | Cabbage | Action threshold fixed schedule 7-14 days | U.S.A. | Effective | Chalfant et al., 1979 |
| Permethrin<br>Methamidophos<br>Methomyl | P. xylostella<br>T. ni | Cabbage | Damage threshold | U.S.A. | Effective for management | Workman et al., 1980 |
| Cypermethrin | P. xylostella | Cauliflower | Population density | India | Complete control | Awate et al., 1982 |
| Fenvalerate | A. rapae | Crucifers | Population density | China | 95-100 % reduction | Chew et al., 1982 |
| Methamidophos<br>Fenvalerate<br>Cypermethrin | P. xylostella | Cauliflower | Population density | India | 90-100 % reduction | Gandhale et al., 1982 |
| Fenvalerate | P. xylostella | Bioassay | Toxic doses | Japan | Susceptible | Miyata et al., 1982 |
| Permethrin | P. xylostella<br>A. rapae<br>T. ni | Fresh market & processing cabbage | Action threshold | U.S.A. | Effective | Shelton et al., 1982 |
| Fenvalerate<br>Methomyl | P. rapae<br>P. xylostella | Cabbage | Action threshold | U.S.A. | Effective | Simonet and Morisak, 1982 |

Table 2.3 (continued)

| Chemical | Pest | Crop | Criteria of application | Country | Comment | Author(s) |
|---|---|---|---|---|---|---|
| Cypermethrin<br>Permethrin<br>Acephate | T. ni | | | | | |
| Permethrin | P. xylostella | Lab. bioassay | Topical application | Malaysia | LD =0.001 ug/animal, antifeedant effect | Teh et al., 1982 |
| Fenofos<br>Diazinon<br>Disulfoton<br>Carbaryl<br>Azinphosmethyl | P. xylostella<br>A. rapae<br>T. ni | Cabbage | Density threshold /dose equivalent | U.S.A. | Effective | Andaloro et al., 1983 |
| Fenvalerate<br>Permethrin<br>Methamidophos<br>Carbaryl | P. xylostella | Broccoli | Scheduled | N.Z. | 19-35 days control | Kumar and Chapman, 1983 |
| Cartap (Padan) | A. rapae<br>P. xylostella | Crucifers | Fixed schedule | China | >90 % control | Mo et al., 1983 |
| D.D.T.<br>Trichlorphon<br>Permethrin<br>Deltamethrin | P. xylostella | Spring cabbage | At 1st true leaf, 10 eggs/ cotyledon, 2-3 leaf stage | U.K. | Good control | Nichols and French, 1983 |
| Permethrin<br>Methomyl | A. rapae | Cabbage | Action threshold | Canada | 95 % control | Sears et al., 1983 |

Table 2.3 (continued)

| Chemical | Pest | Crop | Criteria of application | Country | Comment | Author(s) |
|---|---|---|---|---|---|---|
| Permethrin | P. xylostella<br>A. rapae<br>T. ni | Fresh market cabbage | Action threshold | U.S.A. / Canada | Effective | Shelton et al., 1983 |
| Fenvalerate | P. xylostella<br>A. rapae<br>T. ni | Broccoli | Economic threshold | U.S.A. | Effective with chemigation | Chalfant and Young, 1984 |
| Malathion | L. erysimi/<br>M. persicae | Cabbage | Population density | Taiwan | Effective/ non effective | Feng and Hsio, 1984 |
| Thiometon<br>Malathion | B. brassicae | Cabbage | Population density | India | 62-77 % mortality | Gandhale et al., 1984 |
| Endosulfan | A. rapae<br>P. xylostella<br>T. ni | Cabbage | Economic threshold | U.S.A. | Effective | Kirby and Slosser, 1984 |
| Fenvalerate<br>Permethrin<br>Methamidophos<br>Carbaryl | B. brassicae | Lab. bioassay | Toxic dosage | N.Z. | Effective in the same order | Kumar and Chapman, 1984 |
| Fenvalerate | A. rapae<br>P. xylostella<br>T. ni | Cabbage | Action threshold | U.S.A. | Effective | Leibee et al., 1984 |

Table 2.3 (continued)

| Chemical | Pest | Crop | Criteria of application | Country | Comment | Author(s) |
|---|---|---|---|---|---|---|
| Malathion | M. brassicae | Cabbage | Population peaks | U.S.S.R. | Effective against early instar only | Arkhipov, 1985 |
| Fenvalerate + Malathion | P. xylostella | Cabbage | Field population density | Japan | Failed to control | Makino and Horikiri, 1985 |
| Permethrin | P. xylostella<br>A. rapae<br>T. ni | Fresh market cabbage | Action threshold/ Fortnightly schedule | | Saving in insecticide use | Sears et al., 1985 |
| Omethoate | B. brassicae<br>M. brassicae | Cabbage | Population density | Chile | Significant control upto 32 days | Zuniga, 1985 |
| Permethrin<br>Cypermethrin<br>Deltamethrin<br>Mevinphos<br>Prothiophos<br>Prophenophos | P. xylostella | Lab. bioassay | Toxic dose | China | Cross resistance against pyrethroids organophos-phates | Chen and Sun, 1986 |
| Methomyl<br>Fenvalerate | T. ni<br>A. rapae | Collards | Weekly schedule | U.S.A. | Efficacy : Fenvalerate > methomyl | Tompkins, 1986 |
| Mevinphos<br>Carbofuran<br>Fenvalerate<br>Permethrin | P.xylostella | Lab. bioassay | Toxic doses | Taiwan | Cross resistance | Wang and Feng, 1986 |

## 2.11 Microbial Control of Insect Pests

Insect pathogens have shown promise for many years (Dutky, 1941; Steinhaus, 1947) and continuous efforts have been made to develop them for practical application (Tanada, 1967). Microbial pathogens include bacteria, viruses, fungi, protozoa and nematodes. These either infect the insect population naturally or are applied by man as biological control agents. Detailed accounts of utilization of these agents have been given by Steinhaus (1956, 1963) and Heimpel (1965). Heimpel (1965) outlined the basic characteristics of an effective microbial agent:

> "(i) the microbe should be highly virulent for the target insect and should possess little tendency for variation in this regard ;
>
> (ii) it must be harmless for all other forms of life including beneficial insects, plants and vertebrates and should not affect the parasites and predators that attack the target insect ;
>
> (iii) it should be economical to produce and must be capable of withstanding long period of storage without loosing viability or virulence in order that large stockpiles can be created and
>
> (iv) finally it should act rapidly to prevent heavy feeding damage by the insects either by causing cessation of feeding or by death."

However, with the exception of Bacillus thuringiensis (Berl.), reasonable commercial usage of microbial

insecticides has been limited because of strict regulations for registration, the need for special application techniques, high costs (Falcon and Sorensen, 1976) and their instability in adverse environments (e.g. Leong et al., 1980). Burges and Hussey (1971) also outlined economic barriers impeding the development of practical microbial control of insect pests and mites. Nevertheless, the effectiveness of a microbial agent can be increased through the use of improved strains (Dulmage and de Barjac, 1973; Harper, 1976) or through the manipulation of the environment to enhance the survival (Hall, 1975; Pinnock et al., 1977) and judicious timing of application (Doust, 1974).

### 2.11.1 Use of B. thuringiensis (B.t.)

This bacterium has been used as an effective biocontrol agent for the larval stages of various field crop, forest or public health insect pests. The bacteria produce two major classes of insecticidal toxins i.e. beta-exotoxin and delta-endotoxin (Luthy, 1980). Commercial preparations consist of crystalline protein bodies which are formed during sporulation and are termed parasporal bodies, crystals or deta-endotoxin (Heimpel, 1967). Accounts of B.t. delta-endotoxin applied against lepidopterous pests have been given by Kreig and Langenbruch (1981).

The toxic crystals either cause gut paralysis of the susceptible host or the host is weakend to such an extent that they penetrate the hemocoel and cause lethal

septicaemia (Falcon, 1971).

Factors like solar radiation (UV light) (Griego and Spence, 1978), vapour pressure (Leong et al., 1980), temperature (Ignoffo, 1964) and plant species (Pinnock et al., 1975) have been demonstrated to affect the viability, persistence and pathogenicity under natural conditions. Method of application can also be a critical factor in their success as bio-control agents (e.g. Jerrett et al., 1978).

Field evaluation of B.t. against cabbage lepidopterous pests has been conducted by many workers (Hall and Andres, 1959; Libby and Chapman, 1971; Creighton and McFadden, 1975; Creighton et al., 1981; Krishnaiah et al., 1981) but adequate control was achieved only with regular weekly sprays throughout the growing season (Libby and Chapman, 1971). In contrast, Balagurunathan and Lebrun (1984) found fortnightly sprays to be most effective. No evidence of extensive use of B.t. in Australia is available despite the oft-repeated agroecosystem conservation philosophy prevalent among the agricultural research workers.

### 2.11.2 Use of entomopathogenic nematodes

Entomopathogenic nematodes belonging to two main families, i.e. Steinernematidae and Heterorhabditidae, have been suggested as effective biocontrol agents of insect pests of agricultural and medical importance (see Poinar, 1971; Lam and Webster, 1972). In the family Steinernematidae the genus Steinernema (Syn. Neoplactana, Wouts et al., 1982) is the most important genus which

because of its aggregatory behaviour close to insect larvae (Schmidt and All, 1979), movement upto the $CO_2$ gradient (Gaugler et al., 1980) or excretory product (Schmidt and All, 1979) have made it a potential candidate for biological control agent. Nevertheless their success lies in their lethal effect, ecological adaptation to the host, economic mass scale rearing, storage, ease in application and post application viability (Finney, 1981). Taxonomy, life history and biology of this nematode has been reviewed by Poinar (1972, 1975).

The nematodes form resistant non-feeding third stage juveniles which carry asporous gram negative entomopathogenic symbiotic bacteria, Xenorhabdus nematophilus (Poinar, 1979, Akhurst, 1983). After finding a host the infective juveniles enter the host through mouth, spiracle or anus and enter into the body cavity and release the associated bacteria (Poinar, 1979). The bacteria rapidly multiply and kill the host by septicaemia as well as provide nutritional factors for nematode reproduction while inhibiting the putrefaction of the host cadavar (Akhurst, 1982).

Efficient in vitro mass scale rearing have now become possible as Bedding (1981, 1984) produced 38 millions S. feltiae juveniles per 500 ml flask using shredded plastic foam soaked in pork kidney-beef fat homogenate at the cost of 2 cents per million nematodes.

The environmental conditions to which nematodes are sensitive include high temperature (Schmiege, 1963), moisture stress (Moore, 1965) and solar radiation (Gaugler

and Boush, 1978). Although the potential of nematodes carries more promise against soil inhabiting insects (e.g. Cheng and Bucher, 1972; Kain et al., 1982) than foliage pests (see Gangler, 1981) some antidesiccants and evaporation retardents have been used to increase the retention and viability of nematodes on leaf surfaces (MacVean et al., 1982).

Effectiveness of S. feltiae against larvae, pupae and emerging moth of DM and larvae and pupae of CWB under laboratory conditions has been shown by Morris (1985). Previously, Fox and Jaques (1966) obtained significant mortality of CWB larvae on cabbage heads while Welch and Briand (1961) used nematodes against cabbage pests on cabbage, radish and rutabaga.

There are few examples where nematodes were used in association with other pathogens (Webster, 1972; Bari and Kaya, 1984). However, at present the knowledge of insect-nematode-environment interaction is not sufficient to provide the required understanding of their compatible use with other methods of pest control. Following is the perspective of the steinernematid nematodes as biocontrol agents.

Attributes and liabilities of Steinernematid nematodes as biological control agents of insect pests (Modified from Gaugler, 1981) ;

| Attributes | Liabilities |
|---|---|
| Broad host range | Broad host range |
| Environmental safety | Registration |
| (see also Obendorf *et al.*, 1983) | |
| Laboratory storage | Commercial storage & use |
| High efficacy | Field persistence |
| Economy of *in vitro* mass production (Bedding, 1981, 1984) | Host escape |
| Ease of application | Humeral melanization |
| Power of search | (Poinar and Leuteneggar, 1971) |
| High virulence or rapid action | |
| Compatibility with chemical insecticide | |
| (e.g. Jaques and Morris, 1981; Hara and Kaya, 1983) | |

### 2.11.3 Use of entomopathogenic fungi, *Verticillium lecanii*

This entomopathogenic, deuteromycetous fungus has been reported to control certain species of aphids and scale insects (Baird, 1958) with epizootics and 100% mortality under controlled conditions (Samsinakova and Kalalova, 1976). Natural infection may occur because of irrigation practices, rain splashing or the mobility of arthropods (Hall and Burges, 1979). Like most other entomopathogenic fungi *V. lecanii* requires narrow temperature limits for reproduction and sporulation (Hall, 1981). Mortality of infected insects occurs 3-6 days after infection at 20 °C (Dr. R.J. Milner CSIRO, Canberra, Pers. comm., 1985). Although *V. lecanii* could be used in glasshouse against a

variety of insect pests (Hall, 1981), further knowledge of its application in field and critical factors affecting its infective potential and epizootic capability may lead to its compatible use in integrated control programme.

## 2.12 Integrated Pest Control

An account of chronology and evolution of integrated control concept is presented in Table 2.4. Current interest in integrated pest control all over the world highlights the suspicion that single method approaches (like chemical control only) may not offer a logical and permanent solution to crop protection problems (Brader, 1979). Furthermore, continuing dependence on high levels of pesticide use have been regarded as an impediment against the adoption of integrated strategies of pest control or their management at sub-economic levels (see Doutt, 1972; Corbet, 1981).

Stern et al. (1959) first used the term "integrated control" to explain the complementary use of natural enemies with selective chemicals. The current philosophy of integrated control encompasses the coordinated use of cultural, physical, chemical and biological methods compatible to economic, ecological and toxicological rationale and which assign maximum importance to natural control factors and economic thresholds (Brader, 1979). Integrated control has been defined by the FAO Panel of Experts on Integrated Pest Control (1973) as :

Table 2.4 Chronology and evolution of integrated control concepts.

| Concept | Methodology | Author(s) |
|---|---|---|
| Adoption of the word ecology by Professor Stephen A. Forbes in 1880 | Application of ecological concept in insect pest problem | Metcalf, 1930 |
| Proper and timely treatment | when to apply and not to apply | Woodworth, 1896 |
| Merits and limitations of pesticides and their management | Application of chemical control in conjunction with cultural control | Malley, 1901 |
| Utilization of natural mortality factors | Evaluations of effectiveness of natural enemies | Woodworth, 1908 |
| Integration of cultural and chemical control | Use of damage thresholds, population density, strip poisoning | Hunter and Coad , 1923 |
| Avoidance of secondary pest emergence due to constant use of inorganic chemicals | Emphasis on multilateral insecticide applications | Fletcher, 1929 |
| Use of economic threshold | Regular pest check/scouting | Smith, 1949 |
| Ecological concept of population balance and use of chemical controls | Population regulation by biotic agents and chemical controls | Kennedy, 1953 |
| Ecosystem approach to insect pest problem, natural balance | Utilization of natural parameters to suppress pest population | Smith and Allen, 1954 |
| Integration of biological agents (natural) and selective chemicals | Predators and selective chemical insecticide | Stern et al., 1959 |
| Environmental resistance supplemented with selective pesticides | Climatic influences, natural enemies, host-plant resistance and cultural controls | Pickett and MacPhee, 1965 |
| Manipulation of pest population and their prevention to cause economic injuries. | Utilization of all suitable techniques in a harmonized pattern | Smith and van den Bosch, 1967 |
| Integration of compatible techniques | Development of pest resistant cultivars, selective insecticides and the use of sex attractants | Pathak, 1969 |
| Integrated control strategies | Mass rearing and release of effective natural enemies | Croft and McMurty, 1972; Chin et al., 1974 |
| Mangement of multi-pest situation with integrated control methods | Integration of biological and selective chemical insecticides | Kennedy and Oatman, 1976 |
| Development of an integrated control program for fresh market tomato pests | Weekly application of biological insecticide, twice weekly releases of parasitoids compared with weekly application of chemical insecticides | Oatman et al., 1983 |
| Dynamic programming model of integrated control containing different management alternatives | Use of parasitoids, cultural control by timing the crop harvest and chemical control by insecticides | Shoemaker and Onstad, 1983 |
| Integration of biological and chemical control strategies in a multiple pest agroecosystem | Potential use of synthetic pyrethroids with proper timing, impact of insecticides on predator-prey interaction | Hull et al., 1985 |

> " a pest management system that in the context of the associated environment and the population dynamics of the pest species, utilizes all suitable techniques and methods in as compatible a manner as possible and maintains the pest population at levels below those causing economic injury".

Basically integrated control is aimed at reducing pesticide use as well as to enhance natural and other non-chemical methods to reduce the economically damaging pest population. Lawson (1966) summarized the advantages of integrated control as reduction in pesticidal use, toxic residues and environmental contamination, delay in the development of pest resistance, conservation of natural enemies and possibly reduction in control costs.

Unfortunately, farmers especially monoculturists, employ technological inputs rather than cultural and other non-chemical methods of crop protection (Ogunfowora and Norman, 1973). In this context attempts have always been made to enhance the effectiveness of natural enemies through the use of selective insecticides (Kennedy and Oatman, 1976) but such attempts were often thwarted by the increasing trends of energy inputs aimed at maximizing short term yields (see Webster, 1980).

Due to the temporary nature of high valued horticultural crops and consumer's demands for high quality blemish-free produce, natural enemies alone may not prevent the occurrence of economic damage. Nevertheless, there is a tremendous scope for utilizing compatible chemical and non-chemical strategies for

effective pest control. Kennedy and Oatman (1976) used Dipel, B. thuringiensis var kerstaki, in combination with pirimicarb against multiple pests on broccoli which reduced both aphid and lepidopterous pest populations.

Various chemical insecticides effective for the control of the cabbage pests are bound to have undesirable residues on the consumable cabbage head. Therefore, alternative methods of suppressing the pests should be sought with biological and non-chemical strategies having no undesirable effect on the consumer and the environment. A chronological account of integrated control methods against brassica insect pests has been given in Table 2.5.

The butterflies of the genus Pieris have two subgenus : Pontia whose members hold their wings in a broad 'V' when basking and who have extensive dark areas on the outer margin. In contrast, the butterflies of the subgenus Artogeia adopt a narrower 'V' in basking and have light colouring on the outer margin (Kingslover,1985)*. Pieris rapae has the later characteristics and is presently designated as Artogeia rapae.** This nomenclature follows Higgins (1975) and Howe-(1975)*** who placed palearctic Pieris rapae in the genus Artogeia and also extended this designation to Nearctic representative of this species.

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* Kingslover, J.G.,1985. Butterfly engineering.Scientific Amer .253(2) 90-102.

** Higgins, L.G.,1975. The Classification of European Butterflies, Collins,London.

***Howe,W.H.,1975. The Butterflies of North America.Doubleday Garden City.

Table 2.5 Summary of the literature concerning integrated control/management strategies of insect pests on brassica crops.

| Pests | Control methods/ agents involved | Author(s) |
|---|---|---|
| P. maculipennis | Natural/Biological control | Hardy, 1938 |
| B. brassicae<br>P. maculipennis<br>P. rapae | Selective insecticides parasites/predators | Ripper, 1956a |
| P. maculipennis<br>B. brassicae | Natural control | Pimentel,1961b |
| T. ni<br>P. rapae | Resistant varietes<br>Environmental effect<br>Chemical insecticides | Chalfant and Brett, 1967 |
| B. brassicae | Chemical+Biological | Way et al., 1969 |
| T. ni | T.ni NPV + chemical insecticide | Creighton et al., 1970 |
| T. ni<br>P. rapae<br>P. xylostella | B.t. + chemical insecticide | Creighton et al., 1973 |
| P. xylostella<br>B. brassica | Intercropping tomato with cabbage | Raros, 1973 |
| B. brassicae<br>T. ni<br>P. rapae<br>P. xylostella | Natural enemies,<br>Resistant varieties,<br>Trophic relationship, | Weires and Chiang, 1973 |
| P. rapae | B.t.+chemical insecticide | Creighton and McFadden, 1975 |
| B. brassicae<br>T. ni<br>P. rapae<br>P. xylostella | B.t.+systemic aphicide (pirimicarb) | Kennedy and Oatman, 1976 |
| P. xylostella | B.t.+chemical insecticide | Hamilton and Attia, 1977 |
| B. brassicae<br>T. ni<br>P. rapae<br>Hellula undalis | Thuricide +<br>chemical insecticide | Al-Adil et al., 1978 |

Table 2.5 (continued)

| Pests | Control methods/ agents involved | Author (s) |
|---|---|---|
| E. brassicae | Natural enemies (predators) + chemical insecticides | Finlayson et al., 1980 |
| T. ni<br>P. rapae<br>P. xylostella | B.t.+chemical insecticides | Eckenrode et al., 1981 |
| P. xylostella | Biological control (natural enemies) | Turnock, 1982 |
| P. xylostella | Resistant cultivar | Lin et al., 1983, 1984 |
| Phylotreta spp.<br>Ceutorhynchus pallidactylus<br>A. rapae | Resistant cultivar | Ellis et al., 1984 |
| B. brassicae<br>C. assimilis<br>Dasineura brassicae | Regular pest monitoring on neighbouring brassica oilseed crops | Wheatley and Finch, 1984 |
| P. xylostella | Glossy-leaved resistant cauliflower cultivar | Dickson et al., 1985 |
| P. xylostella | Overhead sprinkler irrigation, Chemical insecticides, Biocontrol agents | Nakahara et al., 1985 |
| P. xylostella | Deterrent plant compounds | Tabashnik, 1985 |
| P. cruciferae<br>B. brassicae<br>A. rapae | Living mulches (grass/clovers) in cabbage crop | Andow et al., 1986 |
| P. xylostella | Overhead irrigation | Tabashnik and Mau, 1986 |
| T. ni<br>A. rapae<br>P. brassicae | Nuclear polyhedrosis virus (NPV)<br>Microsporidian<br>Granulosis virus (GV)<br>B.t. + NPV | Tompkins et al., 1986 |

# CHAPTER 3

# EXPERIMENTAL SITES AND HABITAT CHARACTERISTICS

## 3.1 S.J.F. College Plot

The experimental plot consisted of 31X11m cleared virgin land surrounded by residential college buildings to the north and east and enclosed by a lightly wooded bushy scrub on the west and southern sides. Being isolated from agricultural properties, this site provided conditions free from insecticidal drift and permitted natural build up of insect pest populations and their natural enemies. The vegetation in and around the plot was dominated by plant species belonging to the Graminae, Umbelliferae, Cruciferae, Compositae, Myrtaceae and Rosaceae.

Geographical coordinates of the sites were $42^{\circ}.53'$ S latitude and $147^{\circ}.20'$ E longitude at an elevation of 120m above the sea level. The topographical aspect was north-easterly. The soil was classified as black clay on dolerite with a pH of 6.4. It had a poor drainage characteristic and was liable to dry out in summer. The land was ploughed, levelled and fertilized at the rate of 500 kg/ha of 8:4:10 orchard fertilizer or mixed NPK fertilizers.

At the beginning of the first planting out (August, 1982) a watering line was installed with 3 sprinklers spaced equidistant and operated from the main tap at the Squash Court, S.J.F. College. An electric fence with rabbit wire was installed around the site to prevent possible intrusion from marsupial herbivores.

Ballhead hybrid cabbage was used as the experimental plant because of its moderate green colour, easily distinguishable growth characteristics and smooth textured leaves. Seedlings were either obtained from commercial nursaries or grown by the author in insect-proof glasshouse conditions at the faculty of Agricultural Science. In both cases, these were acclimated with field conditions by putting them outdoor before transplantation. Twenty-five, unless otherwise stated, seedlings were transplanted on raised beds, 12 cm high, with 0.5 m plant to plant spacing in each plot (3×3m). Each plot was separated from the other plot by 1m wide non-experimental area to minimize proximity effects.

Poorly established seedlings were replaced by new ones during the first week and ample supply of water and nutrients provided to sustain rapid growth and development of cabbage plants particularly during the establishment and head formation stages. Weeds were removed by hand hoeing. Temperature and relative humidity were continuously recorded with the help of thermohygrographs placed in a Stevenson's screen in the field 1.3 m above the ground surface. Data for rainfall and other climatic factors were obtained from Meteorological Bureau Hobart situated about 4 km from this experimental site. Monthly averages of temperature, rainfall and sunshine are presented in Appendix 3.1.

Continuity of cabbage crops was maintained and 7 consecutive crops were studied for specific evaluations. Cruciferous weeds acting as alternate food plants for the

insect pests, growing within a 100 m perimeter of the site were wild radish, Raphanus raphanistrum L., hedge mustard, Sisymbrium officinale (L.) Scop and bird rape, Brassica campestris L.. These plants may increase the suitability and longevity of the habitat for the insect population (e.g. Southwood, 1972).

### 3.1.1 General lay-out of experimental plots

The land sloped diagonally across the site, so, there was a need to cope with this source of variation which could not be necessarily removed by row and/or column effects. For this reason the control (untreated) plots were generally arranged in a regular pattern both across rows and down columns to detect and eliminate any major or systematic variation across the experimental area. However, the treatment randomization permitted the possibility of checking whether the response on one treatment plot was affected by the treatment on the neighbouring plots (border effect). Details of the design used in most of the experiments are laid out in Fig. 3.1.

### 3.1.2 Field sampling and counting

In order to obtain estimates of population densities, growth and development characteristics of insects and host plants, observations were carried out at weekly intervals by in situ direct counts. Out of 25 plants/plot the inner 9 plants (3×3) were selected for actual counting while insect populations on the outer 16 plants were graded or coded for rapid estimates. All leaves of the selected

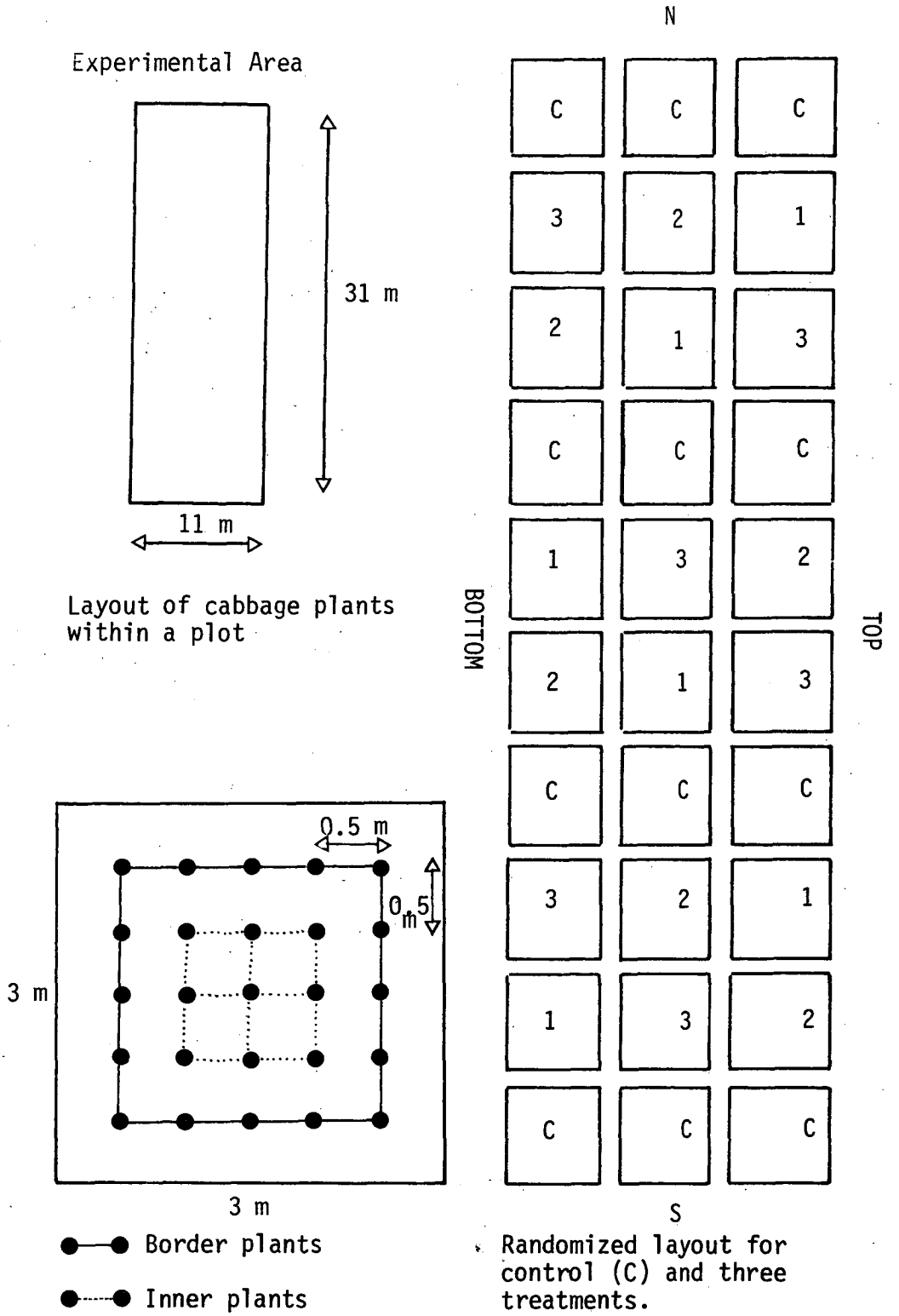



Fig. 3.1. Experimental layout at S.J.F. College.

plant were carefully examined and all stages of each insect present on the plant were recorded. At higher densities of aphids, counting involved approximating the no. of colonies, the size and/or the area covered by the colonies. Diseased stages of any insect were collected and examined in the laboratory for the causal organism involved. Parasitized larval stages of an insect were kept in the laboratory for the emergence of parasitoid or pupation whereas collected pupae were observed for the emergence of the actual adult or its parasitoids. Aphid mummies and cocoons of parasitoids were also collected and reared in the laboratory for the emergence of adult parasitoid. Parasitoids were identified by the taxonomists at Commonwealth Institute of Entomology, London and by the Staff of CSIRO Division of Entomology at Canberra.

## 3.2 Campania Market Garden

This property is located 44 km north-east of Hobart city (Appendix 3.2) at 64m elevation and coordinates 42°.40′ S latitude and 147°.26′ E longitude. The soil was an alluvial clay of seemingly light field texture with good drainage capacity. Average brassica vegetable production area amounted to 6-10 ha per season. Chief varieties of cabbage grown were Ballhead, Greengold, Dutch Hybrid, Savoy King and Red Pickling.

The grower maintained his own nursery stock of cabbage transplants of different varieties. Transplanting was always preferred over direct seeding and thinning and was conducted by a mechanical transplanter consisting of a

furrow-opener and press-wheel which ensured that the seedlings were firmly bedded in the soil. Solid-set line sprinklers were used for irrigation. There were sporadic shortages of irrigation water from the Cole river and summer crops were often threatened with water stress. The topographic profile of this property was prone to N and SE winds. Meteorological information of this site were obtained from the Hobart Meteorological Bureau and are plotted in Appendix 3.3.

The grower maintained a "contract commitment" with a network of wholesale and retail outlets and to ensure a quality product free from insect damage/infestation applied frequent chemical sprays from a tractor-mounted, 2-row boom sprayer with 6 nozzles in each row. Tractor speed was usually kept around 5-6 km/h and 100-150 gallons of aqueous spray solution was used depending upon the growth stage of the crop.

After each harvest the crop residue or stubble was left in the field. Cruciferous weeds such as wild radish, hedge mustard and wild turnip were quite abundant along the side roads and pathways. Hedge mustard was the most persistent weed and was found for a longer period of time. Wild radish was abundant only for a shorter period whereas wild turnip was abundant in mid spring but was absent in late summer. In Sorrel and Richmond, situated within 15 km perimeter from this site, forage crops are principally grown to meet the needs of stock during periods of the year when pasture growth is insufficient. Moreover, the area of brassica forage and oilseed crops (Table 3.1) is

on the increase (Mr. David Secomb, Tasmanian State Development of Agriculture, Pers. comm., 1983).

Table 3.1 : Brassica forage/oilseed crops around Campania (1982-83).

| Location | ha | | |
|---|---|---|---|
| | Turnip | Choumoellier | Rape |
| Sorrel | 44 | 260 | 302 |
| Richmond | - | 148 | 317 |

Source : Australian Bureau of Statistics Tasmania : Crops and Pastures, Tasmania (1982-83), June 1984.

## 3.3 Kingston Market Garden

This property is located 16 km south-west of Hobart city at 42°.58′ S latitude and 147°.19′ E longitude 52 m above the sea level. Its topography consisted of smooth slopes of well drained rich soil of podzol group (red podzolic of basaltic derivation). Average brassica vegetable production was 1-2 ha per season which consisted of crops of cabbage, cauliflower and broccoli. Prominent cabbage cultivars grown were Greengold, Ballhead, Savoy King, Terrific, Beauty and Dutch hybrid.

The grower maintained his own nursery stock of cabbage transplants. The transplanting was carried out either manually or with the help of a mechanical transplanter. A moveable overhead sprinkler was used to irrigate the crops. An ample supply of water was maintained in the farm dam throughout the year. The grower usually competed with other growers in the area to sell his produce

predominantly through wholesale outlets. Aphid damage was considered so low as to warrant no application of aphicide but lepidopteran pests, especially DM was considered to be a serious problem and required preventive insecticidal treatments. Insecticides were applied with the help of a single row boom sprayer. Applications were based upon random decisions regardless of any consideration of quantifiable damage thresholds. For the grower the most important threshold was his own experience. Temperature and rainfall readings were obtained from the records of Meteorological Bureau sub station at Kingston Rotary 2 km from this site. These data are presented in Appendix 3.3.

Throughout the investigation (1982-85), post harvest crop residue was left-over in the field which gave rise to regeneration and resprouting of plants. These plants harboured an uncontrolled pest population which being adjacent to the new crops, posed a permanent threat of infestation. Other brassica forage or oilseed crops in neighbouring areas, within 15 km perimeter, are presented in the following Table 3.2.

Table 3.2 : Brassica forage/oilseed crops around Kingston (1982-83)

| Location | ha | | |
|---|---|---|---|
| | Turnip | Choumoellier | Rape |
| Huon | 10 | - | 97 |
| Port cygnet | - | 16 | 48 |

Source : Australian Bureau of Statistics Tasmania : Crops and Pastures, Tasmania (1982-83), June 1984.

## 3.4 University Farm

The University Farm is located 18 km east of Hobart and consists of 340 ha and is a part of "Craigow" between Cambridge and Richmond. The precise location is 42°.49′ S latitude and 147°.27′ E longitude. The soil is duplex type having sandy loam A horizon overlying mottled brown clay. Before seedling transplantation 8:4:10 fertilizer was applied in the ploughed soil. Weather data were recorded at the Hobart Airport (10 km from the University Farm) and are presented in Fig. 3.4.

## 3.5 CSIRO Research Station

This site is located 16 km east of Hobart at 42°.50′ S latitude and 147°.32′ E longitude 2 m above the sea level on the Hobart Airport. The soil was of sandy loam texture. The experimental plot was surrounded by tall Eucalyptus and Pinus species. An orchard fertilizer (8:4:10) was applied to the soil before the seedlings were transplanted. Synchrony of the growth periods of brassica vegetables and forage crops in the study area is presented in Appendix 3.4. Only one cabbage crop was grown at this site (1984).

# CHAPTER 4

# CABBAGE PEST ABUNDANCE AND CHARACTERISTICS OF INFESTATION

## 4.1 Introduction

This study was undertaken to determine the key factors responsible for regulating the populations of insect pests of cabbage in the field. This required an investigation of the seasonality, population distribution, frequency and intensity of the cabbage pest complex in Tasmania. Attempts were also made to assess the influence of different cultural and environmental events. From this data, the role of factors involved in the population abundance of the associated insects could be hypothesized.

## 4.2 Materials and Methods

Cabbage seedlings (var Ballhead hybrid) 3-4 weeks old with 4-6 true leaves per plant, were transplanted in an area of 300 m at S.J.F. College. Five consecutive crops were maintained from August 1982 - March 1985. Heavy rains and massive slug infestation in the first and second weeks of August 1984 prevented the normal development of the 4th crop which was replaced with an additional new planting.

### 4.2.1 Sampling procedures

In situ counts of insects and other arthropods commenced 7-10 days after planting out and continued at regular intervals until harvest. Several methods were employed to estimate populations as follows :

4.2.1.1 Direct counts on cabbage plants

Counts of insect populations were taken by selecting a whole plant as the sampling unit and a fixed number of plants (9 per plot) was examined for counting stages of the following insect pests and their natural enemies.

Cabbage aphid (CA) : Alate, apterae of all instars, aphid colonies, parasitized and diseased aphids, aphid mummies, parasitoids and predators;

Cabbage white butterfly (CWB): Eggs, Larvae of all instars, pupae, parasitized and diseased larvae and pupae, parasitoids and predators;

Diamondback moth (DM) : Eggs (only on 6 sampling occasions and abandoned later because of time involved in locating and counting them in the field), larvae of all instars, pupae, parasitized and diseased larvae and pupae, parasitoids and predators.

Each crop was divided into 2 quadrats. In each quadrat 54(9×6) plants were examined leaf by leaf at weekly (crop I,II and III) or fortnightly (crop IV and V) intervals. Leaves were also categorized into 3 strata on each plant : upper (youngest), middle (mature) and lower (oldest or senescent). Mean number of leaves per stratum was obtained by dividing the total leaves per plant by 3. Ten plants were selected at random from the plots for counting the average number of leaves in each category. Estimates of within-plant pest distribution, on 3 strata, were made in relation to plant growth and development. Counts were made ensuring minimal disturbance to insects/arthropods that occured on the foliage. Sampling size to obtain estimates

of population means within a 10% standard error was determined by the method of Harcourt (1961 b).

#### 4.2.1.2 Ordinal coding of pest population

Pest populations on the plants (16 per plot) in the border rows were classified using an ordinal coding system. In each quadrat 96(16×6) plants were examined and the populations categorized as low, moderate and high. The classification matrix for degree of infestation is shown in Table 4.1. Comparisons between direct counts and coded ordinal estimates were made to ensure that the direct counts on inner rows reliably represented the whole plot or crop.

#### 4.2.1.3 Measurement of the activity of insect pests and natural enemies by field trapping

Field measurement of the activity of insect pests and their key and potential natural enemies was made with the aid of appropriate trapping devices. It was assumed that during each trapping interval a comprehensive proportion of the active animals per unit crop area was caught. However, major interpretations were based upon the relationship between trapping efficiency and the relative temporal abundance of the insects in their natural habitat. The following trapping devices were employed :

##### 4.2.1.3.1 Sticky traps

Flight and immigration activity, as an indicator of the abundance and potential infestation of insect pests

Table 4.1 Ordinal coding system of populations of cabbage insect pests.

| Insect | Stage | Population code | Ordinal weight | Definition |
|---|---|---|---|---|
| Cabbage aphid | Alate/ apterae | Low | 1 | 1 alate or 1-5 apterae or 0.5 cm diameter colony |
| | | Moderate | 2 | 2-5 alates or 6-25 apterae or 1cm diameter colony |
| | | High | 3 | >5 alates or >25 apterae or >1 cm diameter colony |
| Cabbage white butterfly | Egg | Low | 1 | 1 egg |
| | | Moderate | 2 | 2-3 eggs |
| | | High | 3 | >3 eggs |
| | Larva | Low | 1 | 1 small larva (1st-2nd instar) |
| | | Moderate | 2 | 2 small larvae (1st-2nd instar) or 1 large larvae (3rd-5th instar) |
| | | High | 3 | >2 small larvae (1st-2nd instar) >2 large larvae (3rd-5th instar) |
| Diamond-back moth | Larva/ pupa | Low | 1 | 1 larva (1st-4th instar) / pupa |
| | | Moderate | 2 | 2 larvae/pupae |
| | | High | 3 | >2 larvae/pupae |

and their natural enemies, was estimated with 4 sticky traps around each plot. These were made of clear plastic plates (13×13 cm) attached to wooden stakes 30 cm above the crop. The plastic sheets were coated with a sticky paste (cf. Appendix 4.1) which captured insects. Trapped insects were removed with a coarse camel hair brush soaked in a solvent (kerosene or petroleum ether) and transferred to 80% ethanol for storage.

4.2.1.3.2 Modified Moericke traps

The traps, a modification of the common Moericke trap (Moericke,1951), consisted of hard-plastic trays (45×30×13 cm) of Lemon colour coded B.C.C.52 on the British Colour Council Standard (The British Colour Council, 1951).

The traps were filled to a depth of 10 cm with a water + teepol (0.5%) + formaldehyde (2%) mixture and placed 7 m away from the experimental plots in each ordinal direction. Normally, they were serviced at least once per week which involved removal of trapped fauna and refilling the traps with new solution.

The following assumptions were made when interpreting the relationship between the trapped species and their temporal abundance :

(i) If a species was caught in a trap, that species was assumed to be present in the crop but failure to catch that species did not indicate its absence;

(ii) In the case of inconsistent catches of a

species between different trapping occasions, the species was assumed to be relatively rare at low-catch periods. Alternatively, if a species was caught consistently over a long period of time with marked peaks extending over more than one week's catch then it was assumed to signify a true population change (Hughes et al., 1964).

#### 4.2.1.3.3 Pitfall traps

Pitfall traps consisted of 0.5 l plastic cups (12 cm deep) which were buried in the soil within rows between the plots and partially filled with a water+teepol (0.5%)+formaldehyde (5%) mixture. An aluminium cover (16 cm in diameter) was positioned approximately 5 cm above the cup to protect its contents from evaporative losses and flooding during sprinkler irrigation. All collected arthropods were identified and recorded either in the field or in the laboratory on weekly basis. Their temporal abundance was regarded as an indication of their seasonal activity.

Confirmatory tests on the potential predators of cabbage pests were not conducted because they involved lengthy gut-content examination (e.g. Sunderland and Vickerman, 1980) and laboratory bioassays.

#### 4.2.1.3.4 Pheromone traps

The relationship between catches of male DM moths and

crop infestation was studied by using pherocon traps (No. 50-3304-81, Zoecon Corporation, Palo Alto, California, U.S.A), at the S.J.F. College plots. Rubber caps (code 3139) impregnated with synthetic chemical lure (code DBM 2379123 Zoecon Corp.) were attached to the lower section of the traps. The traps were assembled according to the manufacturer's instruction and positioned on wooden stakes (1 m) with aluminium wire (Fig. 4.1).

The earliest peak in flights of moths, the average no. of flights and their durations were determined. Trapping started in December 1983 and lasted until December 1985. The flight/activity of the moth was monitored both within (interior) and outside (exterior) of the crop. The interior traps (n=3) were positioned at 3 equidistant grids (9 m apart) usually in a V-pattern and kept 50-60 cm above crop canopy. The outer traps (n=2-3) were placed about 30-40 m away from the nearest corner of the cabbage field to spot outdoor activity of the moth. All traps were set in east-west direction to facilitate optimum captures. Traps were checked every 3-7 days and the number of DM moths and other insects were recorded. All trapped insects were removed from the trap after each counting. The sticky bottom was changed every 4-6 weeks but more frequently during peak moth activity or wet weather. Attractant caps were replaced every 4 weeks and the older caps were disposed away from the experimental area.

Non-target lepidopterous insects were identified by the staff of Tasmanian Department of Agriculture at Hobart. Temporal relationship between mean catches and

Fig. 4.1. Experimental site site at the S.J.F. College (1982-85).

Diamondback moth pheromone trap in the cabbage plot is shown below.

mean larval population were also determined by comparing moth population per trap per week with a lag of 7-24 days to the subsequent larval populations (e.g. Baker et al., 1982).

#### 4.2.1.3.5 CWB female attractant

Virgin CWB females were tied to fine threads and hanged to the border posts of cabbage field. Observations were made whether CWB males in the field showed any attraction to the females.

### 4.2.2 Temporal variation in pest abundance and its relationship with weather conditions

An attempt was made to correlate population levels of all 3 pest species with climatic variables. These were mean temperature, mean relative humidity and mean rainfall recorded during respective crop seasons. The combined effect of temperature-humidity and temperature-rainfall was investigated by plotting temperature-humidity index (T/H) and temperature-rainfall index (Tm/R) against concurrent population levels of individual pest species. The following formulae were employed to calculate each index (Morris, 1963).

$$\text{T/H index} = \frac{\text{Mean daily temperature for time interval X}}{\text{Mean relative humidity for the same interval}}$$

$$\text{Tm/R index} = \frac{\text{Mean maximum temperature for time interval X}}{\text{No. of rainy days during the same interval}}$$

### 4.2.3 Physiological time and population generations

Field population data of the 3 pest species were related to accumulated degree-days ($^{\circ}D$) or heat units (HU's) obtained concurrently from the field and the theoretical number of possible generations was determined. Degree-days were calculated on a daily basis using the method described by Arnold (1960) i.e.

$$\text{Degree-days} = \frac{(\text{Tmax} + \text{Tmin})}{2} - \text{LDT}$$

Where
Tmax = Daily maximum temperature
Tmin = Daily minimum temperature
LDT = Lower developmental threshold ($^{\circ}C$)

Only lower threshold values were involved in this computation as the maximum temperature rarely crossed the upper tolerance limits which could be presumed as detrimental to the insect's survival in the field. When the minimum temperature was below the threshold temperature, adjustments were made using the methods of Arnold (1960) and Baskerville and Emin (1968). Temperature data (Sep.82 - Sep.83) obtained from the field thermohygrographs was considered independent of other environmental parameters such as relative humidity, wind speed, rainfall, etc. It was also assumed that the accumulated degree-days could alone explain the variations in the biological responses of insects and that the responses of plant and insects to temperature were linear over the whole growth period (e.g. Andrewartha and Birch, 1954; Baskerville and Emin, 1968).

Only one documented developmental threshold value was

used for all stages of a subject species to calculate the degree-days required for one generation. The dominant peaks of those stages representing the range or point of maximum occurrence in the crop were taken into account to calculate the degree-days per generation. Consequently, the population trends together with information on the frequency of pre-adult stages were compared to the environmental quality.

The following determinations of physiological time were used to estimate the number of generations of individual pest species.

| Pest | Stages involved per generation | Physiological time required (degree-days) | Reference |
|---|---|---|---|
| B. brassicae | 1st-4th instar + adult apterae or alate | 250 | Hughes,1963 |
| A. rapae | Egg-pupa | 211 | Davies and Gilbert, |
| | Pupa-adult | 116 | 1985 |
| P. xylostella | Egg - adult | 293 | Butts and McEwen, 1981 |

### 4.2.4 Within-field distribution and statistical analyses of dispersion

Spatial dispersion patterns of all 3 insect pests on cabbage plants were determined by calculating dispersion indices. These indices included the variance/mean ratio, mean crowding, Lloyd's patchiness index (Lloyd, 1967) and Green's coefficient of dispersion (Green, 1966). Calculations were made at each counting date (crop I and

II). The following formulae were used to calculate the dispersion indices ;

(i) Variance/Mean = $S^2/\bar{X}$

(ii) Mean crowding= $\overset{*}{X} = \bar{X} + (S^2/\bar{X})-1$

(iii) Lloyd's patchiness index = $\overset{*}{X}/\bar{X}$

(iv) Green's coefficient of dispersion= $C_x = \dfrac{(S^2/\bar{X})-1}{\Sigma X-1}$

where $S^2$ = Variance

$\bar{X}$ = Mean = $\dfrac{\text{Total insects counted on plants}}{\text{Total plants examined}}$

$\Sigma X$ = Total number of insects counted

Taylor's regression of spatial dispersion pattern (Taylor, 1961, 1965, 1984) which considers that variance is proportional to a fractional power of the mean, is given by :

$$S^2 = a\bar{X}^b$$

where a and b were the intercept and slope respectively on a plot of log variance ($S^2$) against log mean ($\bar{X}$). Another regression method introduced by Iwao (1968) was calculated by :

$$\overset{+}{X} = \alpha + \beta\bar{X}$$

where

$\alpha$ = the intercept on the ordinate

$\beta$ = the slope of the regression line obtained

These calculations were done by Sharp El-512

scientific calculator. Interpretations of different indices used to evaluate the spatial distribution of cabbage pests are presented in Table 4.2.

### 4.2.5 Parasitism as a mortality factor

Parasitism was calculated from direct field counts where numbers of parasitized individuals were compared with healthy individuals and the result expressed as percentage parasitism. Levels of parasitism were also calculated by rearing the field collected individuals in the laboratory. Depending upon the number of individuals or the size of infestation, parasitized aphid mummies were isolated from the plant and brought back to laboratory (insectary) and usually reared at 20±5 °C. A varying number of live aphids was also collected from the non experimental or bordered plants during each counting and reared under insectary conditions on cabbage leaf discs placed in 9-cm diameter plastic petri dishes. The proportion of aphids which turned into mummies was used for calculating the number of live parasitized aphids. This number was then added to the number of mummies (%) in the field to obtain the percentage parasitism as follows:

$$\text{Field parasitism (\%)} = \frac{\text{no. of intact mummies observed}}{\text{no. of (intact mummies + live aphids)}} \times 100$$

$$\text{Laboratory parasitism (\%)} = \frac{\text{no. of aphids turned into mummies}}{\text{total no. of aphids reared}} \times 100$$

Table 4.2 Indices of dispersion employed to describe the spatial distribution of cabbage pests on cabbage crops.

| Dispersion/ Regression Index | Symbol(s) | Value | Distribution Pattern |
|---|---|---|---|
| Coefficient of dispersion (Variance/mean) | $\frac{S^2}{\bar{X}}$ | >1 | Aggregated (clumped) |
| Mean Crowding | $\overset{*}{X}$ | =1 | Random |
| Lloyd's patchiness index | $\frac{\overset{*}{X}}{\bar{X}}$ | <1 | Uniform |
| Green's coefficient of dispersion | Cx | Approaching 1.0 or = 1.0<br>= 0.0 | Aggregated<br>Random |
| Taylor's power law | $S^2 = a\bar{X}^b$ | b>1<br>b=1<br>b<1 | Aggregated<br>Random<br>Uniform |
| Iwao's regression | $\overset{*}{X} = \alpha + \beta\bar{X}$ | β>1<br>β=1<br>β<1 | Aggregated<br>Random<br>Uniform |

$$\text{Total parasitism (\%)} = \frac{\text{no. of(intact mummies observed + live parasitized aphids)}}{\text{no. of (intact mummies observed + live aphids)}} \times 100$$

Immature stages of CWB and DM showing symptoms of parasitism were removed from the plants during normal counting routine and were reared in either 16-dram glass vials or 9-cm diameter plastic petri dishes. Parasitoids emerging from the reared individuals were recorded and identified. No parasitoid was tested for its parasitic potential in the laboratory. Similar procedures were adopted in subsequent studies. Any disease incidence was recorded and the causal organisms identified from relevant keys (King and Humber, 1981).

## 4.3 Results

### 4.3.1 Efficiency of the sampling methods

#### 4.3.1.1 Border effects

Shortly after transplanting, cabbage plants were attacked by immigrant CA and gravid females of CWB and DM. Subsequent breeding led to population build-up. The results of initial sampling by direct counts of insects on the border and inner rows are given in Table 4.3. The population densities of all insects in these two perimeters were similar suggesting border effects were not important in colonization by the pests.

#### 4.3.1.2 Direct counts versus ordinal coded estimates

Relationships between the population estimates taken

Table 4.3 Comparison of pest population estimates by direct counts on plants in the border and inner rows in cabbage crop at S.J.F. College.

| Date of counting | Area | No.plants sampled | No. per plant ± S.E. | | | |
|---|---|---|---|---|---|---|
| | | | *B. brassicae* | | *A. rapae* | |
| | | | Alate | Apterae | Eggs | Larvae |
| 22.9.82 | Border rows | 96 | 0.14±0.34 | 0.25±0.61 | 0.78±0.53 | 0.02±0.14 |
| | Inner rows | 54 | 0.13±0.57 | 0.22±0.48 | 0.77±0.57 | 0.02±0.13 |
| 29.9.82 | Border rows | 96 | 0.82±0.48 | 1.0 ±0.97 | 1.37±0.83 | 0.04±0.20 |
| | Inner rows | 54 | 0.81±1.44 | 0.9 ±1.2 | 1.57±1.00 | 0.04±0.18 |
| 6.10.82 | Border rows | 96 | 0.13±0.33 | 0.20±0.67 | 2.06±2.23 | 0.15±0.43 |
| | Inner rows | 54 | 0.11±0.55 | 0.18±0.67 | 1.96±1.84 | 0.13±0.33 |
| | | | *P. xylostella* | | | |
| | | | Eggs | | Larvae | |
| 13.10.82 | Border rows | 96 | 0.19±0.86 | | - | |
| | Inner rows | 54 | 0.19±0.96 | | - | |
| 20.10.82 | Border rows | 96 | 0.19±0.86 | | 0.10±0.33 | |
| | Inner rows | 54 | 0.19±0.96 | | 0.09±0.40 | |
| 27.10.82 | Border rows | 96 | 0.18±0.71 | | 0.29±0.59 | |
| | Inner rows | 54 | 0.14±0.74 | | 0.31±0.54 | |
| 3.11.82 | Border rows | 95 | 0.10±0.71 | | 0.52±0.79 | |
| | Inner rows | 54 | 0.06±0.40 | | 0.52±0.75 | |

by direct counts and ordinal coding are shown in Figs. 4.2-4.7. A poor correlation (r=0.24) was obtained between the counted and coded populations of alate CA. In contrast, counted and coded populations of apterae CA were found to be significantly and positively correlated (r=0.798). Similarly, the counted and coded populations of CWB eggs and larvae were also strongly correlated (r=0.82 and r=0.83 respectively). Counted and coded populations of DM larvae were strongly correlated (r=0.91) whereas pupal populations in these two methods showed a rather weaker correlation (r=0.66).

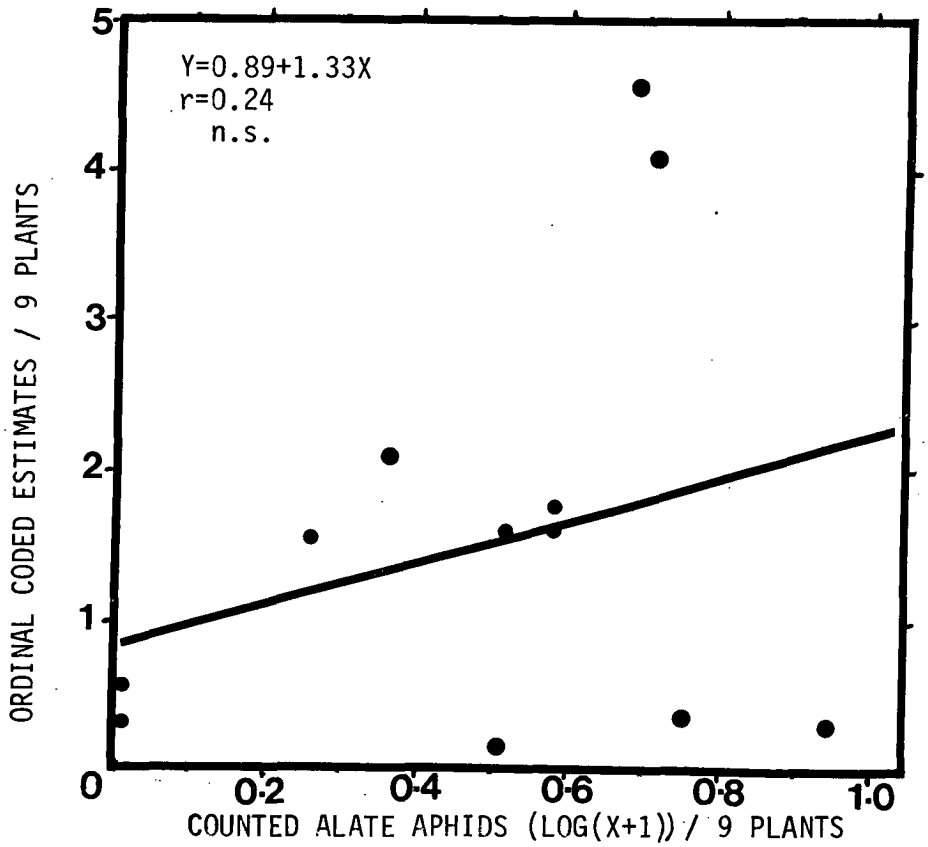



Fig. 4.2. Relationship between counted and ordinally coded populations of alate cabbage aphid at S.J.F. College cabbage plots (1982-83).

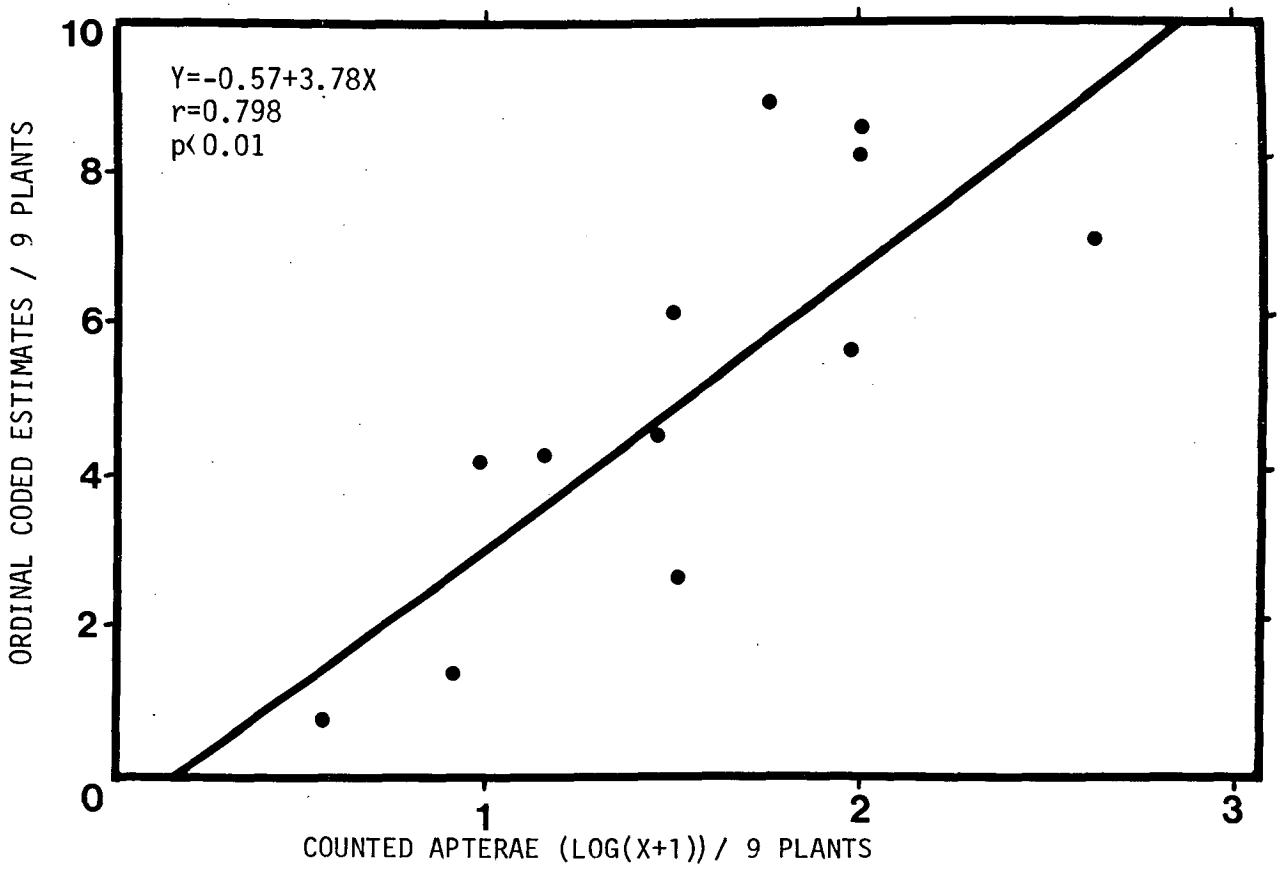



Fig. 4.3. Relationship between counted and ordinally coded populations of apterae cabbage aphid at S.J.F. College plots (1982-83).

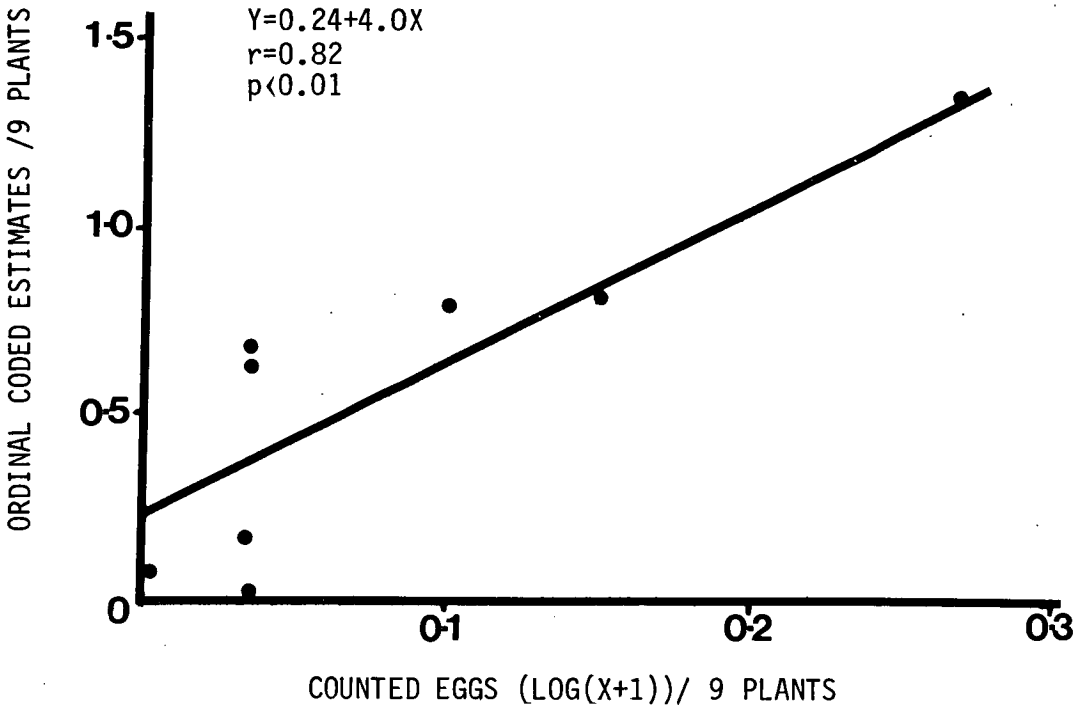



Fig. 4.4. Relationship between counted and ordinally coded populations of CWB eggs on cabbage plants at S.J.F. College plots (1982-83).

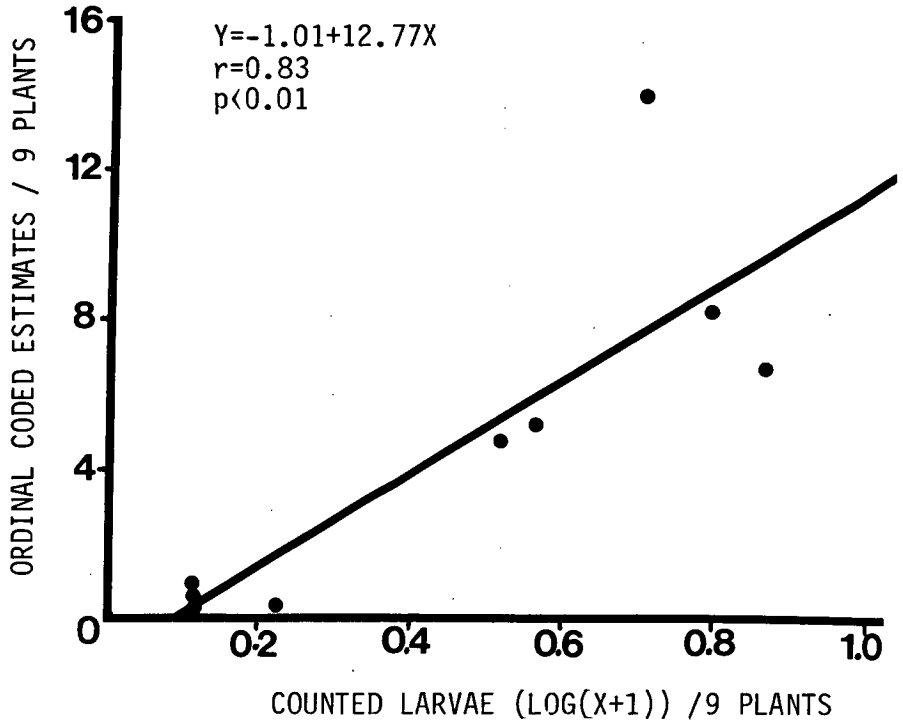



Fig. 4.5. Relationship between counted and ordinally coded populations of CWB larvae on cabbage plants in S.J.F. College plots (1982-83).

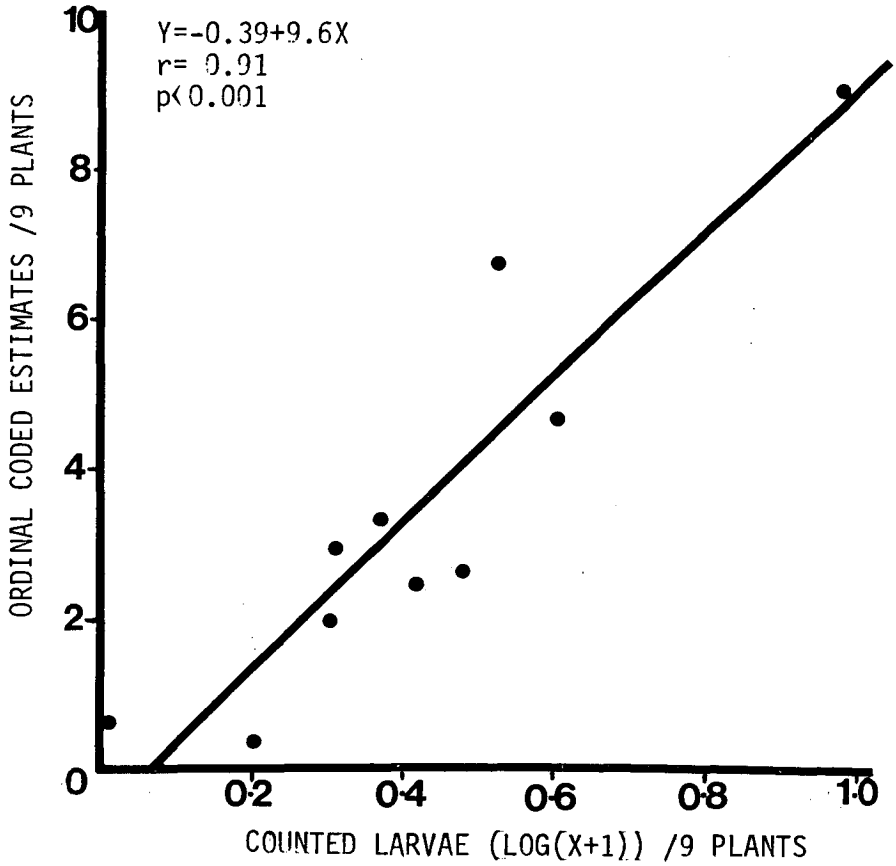



Fig. 4.6. Relationship between counted and ordinally coded populations of DM larvae on cabbage plants in S.J.F. College plots (1982-83).

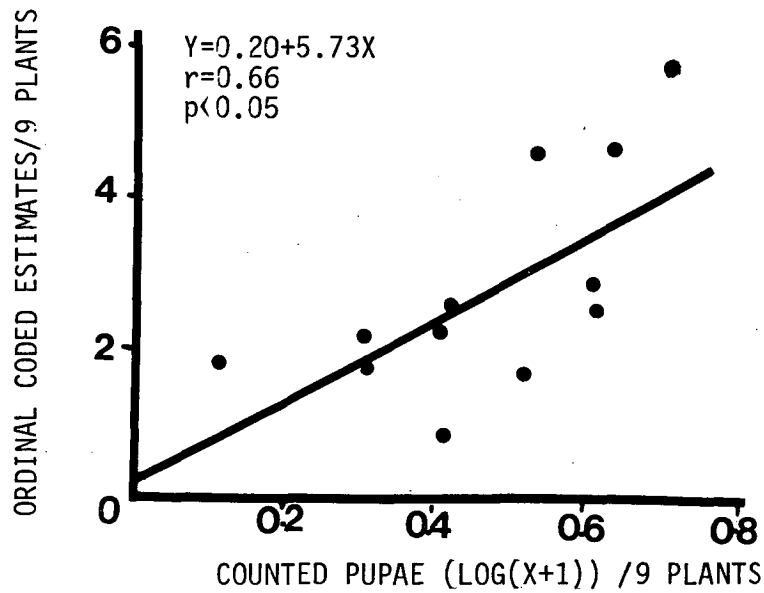



Fig. 4.7. Relationship between counted and ordinally coded populations of DM pupae on cabbage plants in S.J.F. College plots (1982-83).

Direct counting of insect numbers on a plant took approximately 2-5 minutes compared to 0.5-2 minutes for coding the insect population on the same plants.

### 4.3.2 Seasonal population abundance and weather conditions

The data on seasonal abundance and sequence of appearance of the 3 cabbage pests are represented in Fig. 4.8.

#### 4.3.2.1 Cabbage aphid

Aphid populations were always initiated by immigrant alates. These alates appeared soon after transplanting and were the primary source of infestation. Although the alate aphids were not equally abundant at all times of the year they displayed distinct trends of activity from the onset of spring (August-September) until early autumn (March) each year. However, their population remained relatively low during November and December but showed a rapid increase to peak levels in early February (Fig. 4.8, crop v). The post February flights of alate aphids gave rise to persistent populations of both alate and apterous aphids throughout the autumn till mid winter (April-July). However, aphid colonization and population growth were comparatively slower at this time than in the spring or summer (September-Febuary).

Alate colonization and subsequent production of apterous aphids were seriously suppressed by torrential and continuous rains accompanied by stormy winds during

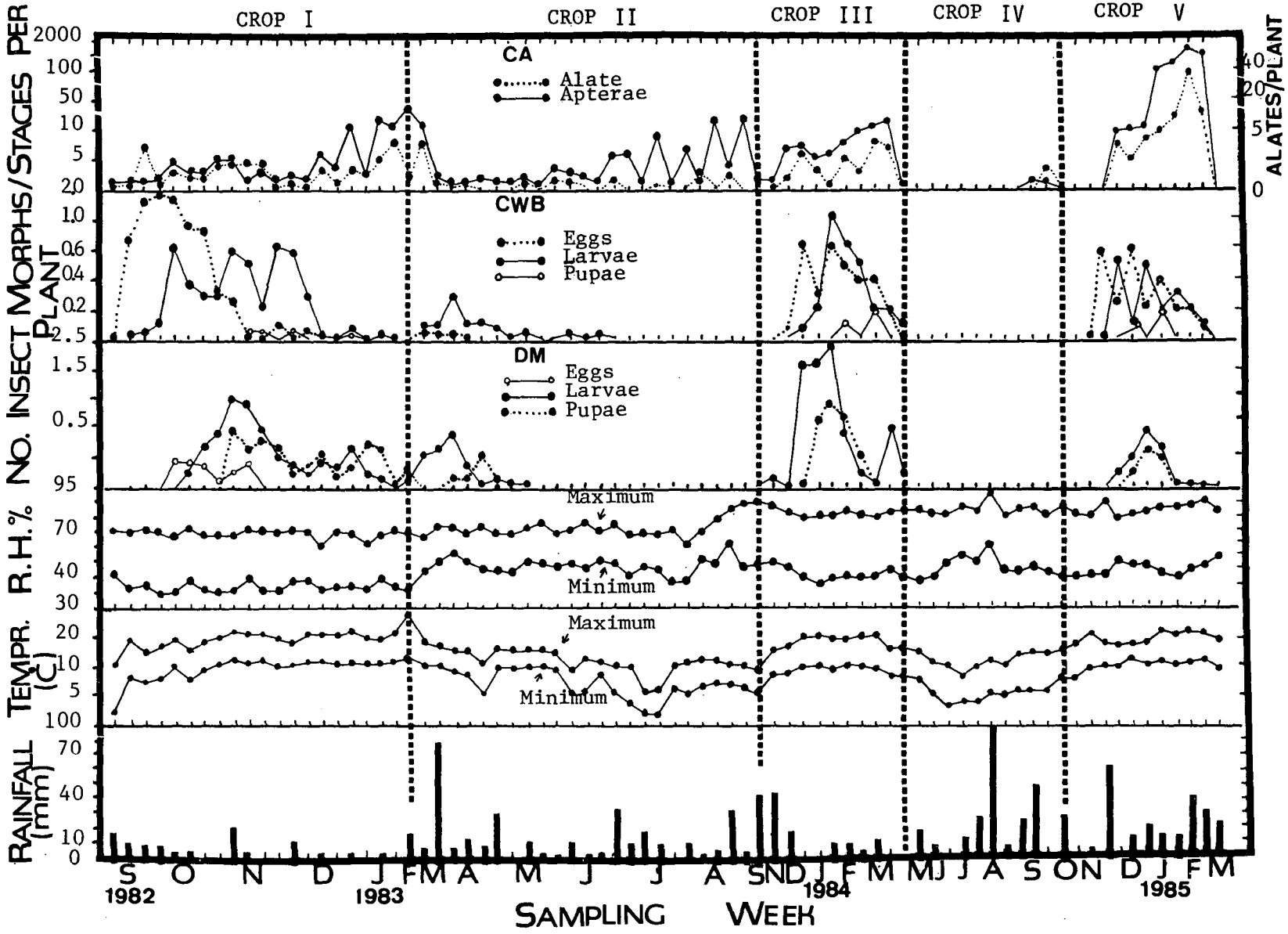



Fig. 4.8. Seasonality of insect pests on cabbage and climatic conditions at S.J.F. College (1982-85).

crop IV (July-September). These climatic factors appeared to drastically restrict immigration and colonization by alates and caused disturbance and dislodgment of newly born aphids.

During crop III and crop V populations increased rapidly as large numbers (upto 1450 per plant) of apterous, viviparous females were produced by the colonizing alates. Generally, both alate and apterous aphids reached their respective population peaks when the cabbage crop approached the head-formation stage and lasted till crop maturity. However, in crop III and crop V a fungal pathogen, Erynia neoaphidis (Entomophthora aphidis), infected the aphid colonies and almost all aphids exhibited the characteristic greyish mouldy symptoms of the disease. Mortality, particularly in crop V was so acute that dead and dying aphids were washed off by subsequent rains. Warm, moist weather conditions with a narrow range of temperature (Min. 12°C - Max. 19.5°C) experienced at the start of epidemic, appeared to be of vital importance in the development of the disease epizootics.

The alate and apterous aphid population levels in all crops were positively correlated (Fig. 4.9). In winter crop (crop II), cold weather lowered the reproductive rate and suppressed the incoming flights of aphids which contributed to the weakest correlation between alate and apterous aphids during the winter season.

Although the timing of aphid population increases in spring and summer were highly variable (crop I, III) the

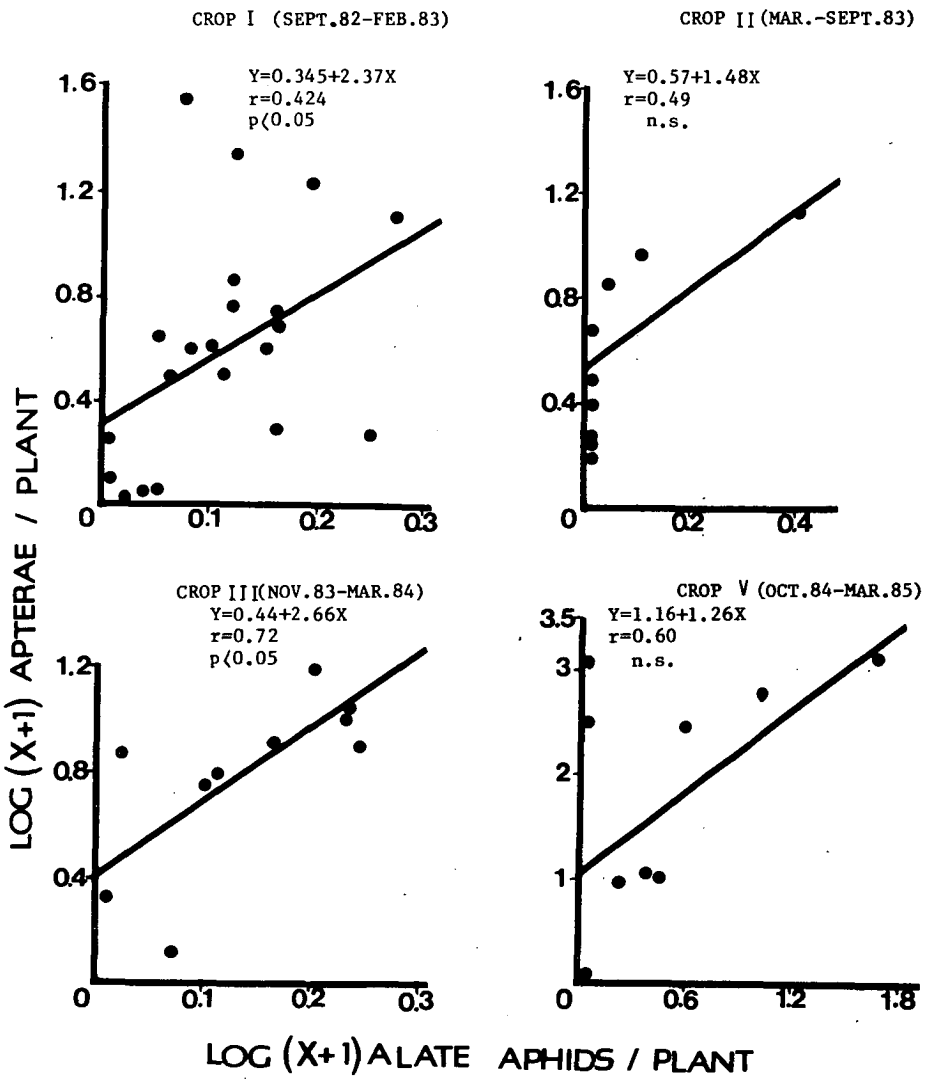



Fig. 4.9. Relationship between alate and apterae cabbage aphid occurrence in cabbage crops at S.J.F. College (1982-85).

overall climatic conditions were favourable to attain population maxima. Smaller population peaks were also observed during crop I and II which indicated non-discrete reproduction periods with considerable overlapping of generations.

Changes in rainfall, temperature and relative humidity (%) are shown in Fig. 4.8. Individually, temperature and rainfall had positive and significant correlations with apterous and alate aphids respectively in crop I and II (simple correlation, Table 4.4). However, the combined effect of these parameters (multiple correlation) showed a positive and significant correlation with apterous aphid population levels in crop I. Rainfall alone or in combination with temperature and humidity was positively correlated with alate aphid population levels in crop II. Although the combined effect of temperature, relative humidity and rainfall did not show significant correlations with either alate or apterous aphids in crop III and V there is a strong evidence that the effect of these climatic variables alone or in combination, was not to limit cabbage aphid abundance.

Figure 4.10 represents the relationship between the temperature-humidity (T/H) and temperature-rainfall (Tm/R) indices and the seasonal population levels of alate aphids. Except in crop V, no significant and/or consistent relationships were obtained. The optimal ranges of T/H and Tm/R indices corresponding to the alate aphid population maxima were found to be 0.2-0.3 and 0.0-5.0, respectively. The Tm/R index range showed that the activity of this

Table 4.4 Matrix of correlation (r) of cabbage aphid abundance to key environmental variables at S.J.F. College (1982-85).

| Crop No. | Period (season) | Aphid morph | Simple correlation[+] T | R.H. | Rf | Multiple correlation T,R.H.,Rf | T,R.H. | T,Rf |
|---|---|---|---|---|---|---|---|---|
| 1 | Sept.82-Feb.83 (Spring-Summer) | Alate | .080 | .011 | -.167 | .198 | .107 | .173 |
| | | | * | | | ** | ** | ** |
| | | Apterae | .535 | -.037 | .252 | .568 | .541 | .561 |
| | | | | | *** | *** | | *** |
| 2 | Mar.83-Sept.83 (Autumn-Spring) | Alate | .440 | -.219 | .953 | .968 | .443 | .964 |
| | | Apterae | -.232 | -.076 | .76 | .328 | .274 | .254 |
| 3 | Nov.83-Mar.84 (Summer-Autumn) | Alate | -.303 | .640 | .153 | .684 | .641 | .303 |
| | | Apterae | -.002 | .356 | .046 | .422 | .405 | .052 |
| 5 | Oct.84-Mar.85 (Spring-Autumn) | Alate | .212 | .260 | .184 | .448 | .295 | .303 |
| | | Apterae | .385 | .230 | .007 | .395 | .385 | .052 |

+ : Abbreviated as T : Temperature, R.H : Relative humidity , Rf : Rainfall
* = P< 0.05, ** = P< 0.01, *** = P< 0.001

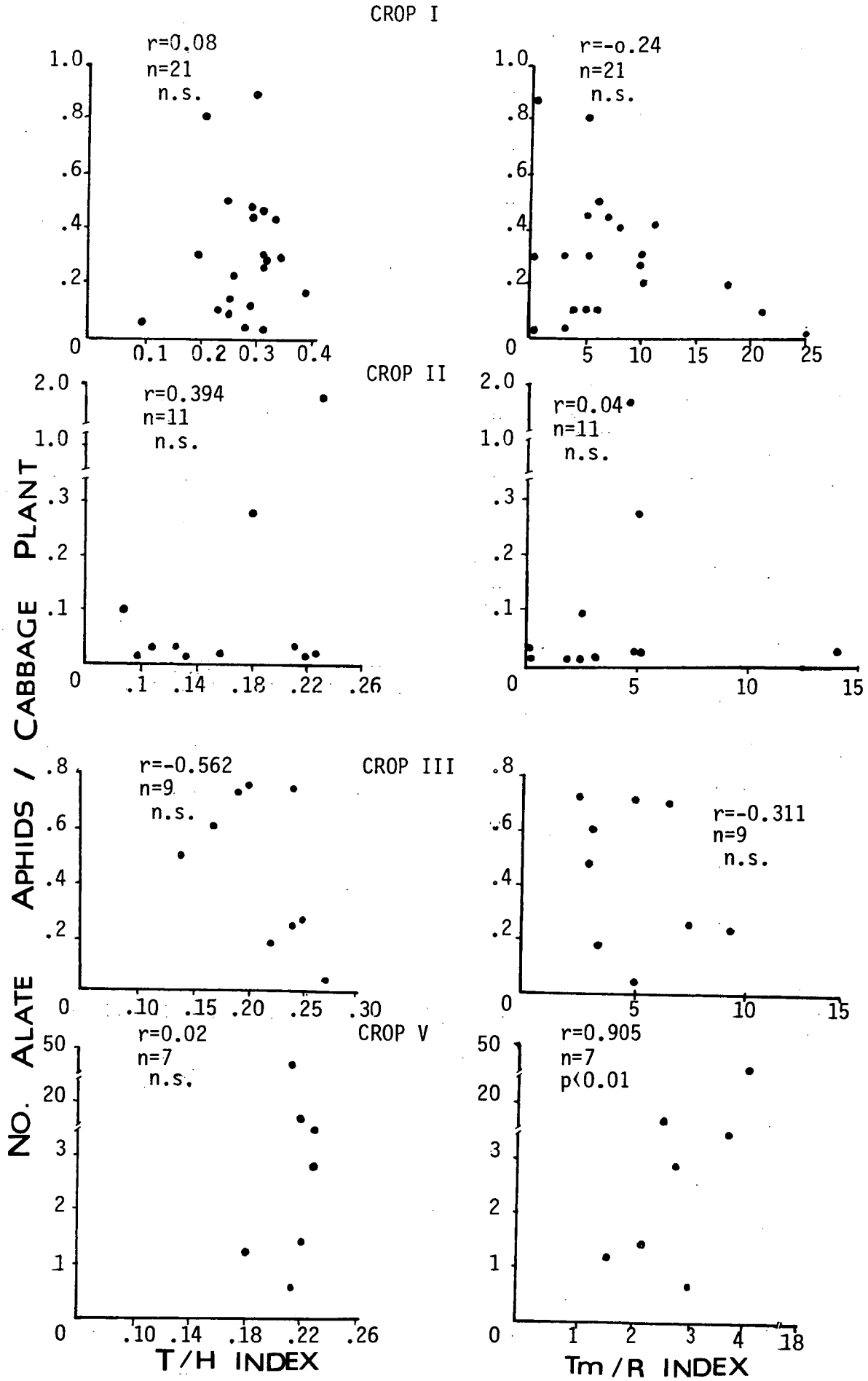



Fig. 4.10. Alate CA populations plotted against temperature-humidity (T/H) and temperature-rainfall (Tm/R) indices at S.J.F. College cabbage plots(1982-85).

morph occured in the absence of rain till the mean maximum temperature/no. of moderately rainy days equalled 5.

Figure 4.11 shows the influence of T/H and Tm/R on the population levels of apterous aphids. Populations were significantly correlated ($P<0.05$) with T/H and Tm/R indices in crop I and V respectively. In other crops, inconsistent and non-significant correlations were obtained. Thus it was not possible to generalise on the relationship between the aphid populations and either one or both indices. The optimum ranges of T/H and Tm/R indices compatible to the apterous aphid population maxima were found to be 0.12-0.4 and 2-6 respectively with the exception of crop I where the Tm/R index value for population peak was 25 because of a very dry and relatively low rainfall season.

#### 4.3.2.2 Cabbage white butterfly

Seasonal abundance of CWB eggs, larvae and pupae is summarized in Fig. 4.8. The major egg peaks of 0.5-2 per plant were recorded from mid October to mid December. In crop I egg numbers increased to a peak of almost 2 eggs/plant in mid October followed by a gradual decline until mid April. In crop III and V egg peaks were apparent in mid December. From May-August the crops remained free of eggs (crop II and IV).

Butterflies were first observed in early September, the first eggs were recorded in mid September and larvae

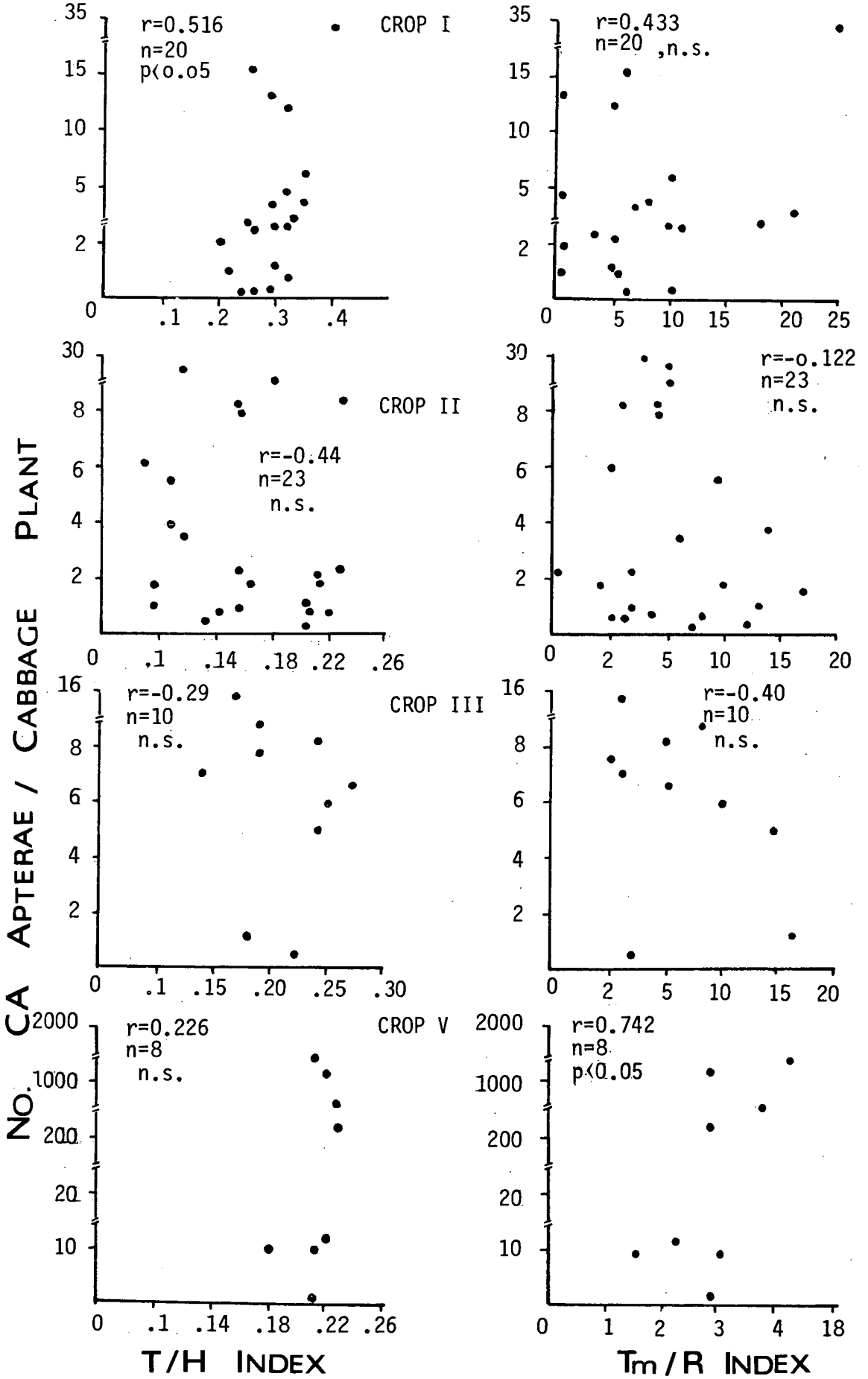



Fig. 4.11. Apterous cabbage aphid populations plotted against temperature-humidity (T/H) and temperature-rainfall (Tm/R) indices at S.J.F. College cabbage plots (1982-85).

were found initially in the 4th week of September. The fluctuation in larval numbers were marked by characteristic peaks (0.7-1.1 larvae per plant) which occured during early December and mid January respectively. Interestingly, in crop II a small proportion of the overall larval population (1.6-6.6%) was recorded in the colder months of May-June. However, larvae were absent from crop IV at the same time of the year.

Both egg and larval populations tended to decline as the cabbage plants approached maturity (head formation) stage. A few pupae (0.16-0.33 per plant) were found from mid November to early January and pupal density was not related to earlier larval populations. Occasionally, pupae were encountered on non-cruciferous weeds present on the borders of the experimental field.

Persistent and relatively high rainfall in August-September suppressed both egg and larval population in crop IV. No epizootics of larval pathogens were noticed in any crop except in crop II when 3 moribund larvae were collected in late April. The causal agent was a granulosis virus. Figure 4.12 illustrates the relationship between the egg population and subsequent larval population occured in 14 days after, in different crops. Both populations were significantly correlated ($P<.001$) in crop II and crop V. Although the relationships between egg and larval populations in crops I and III were not highly significant they were positively related to varying degrees.

Table 4.5 represents the relationship of weather

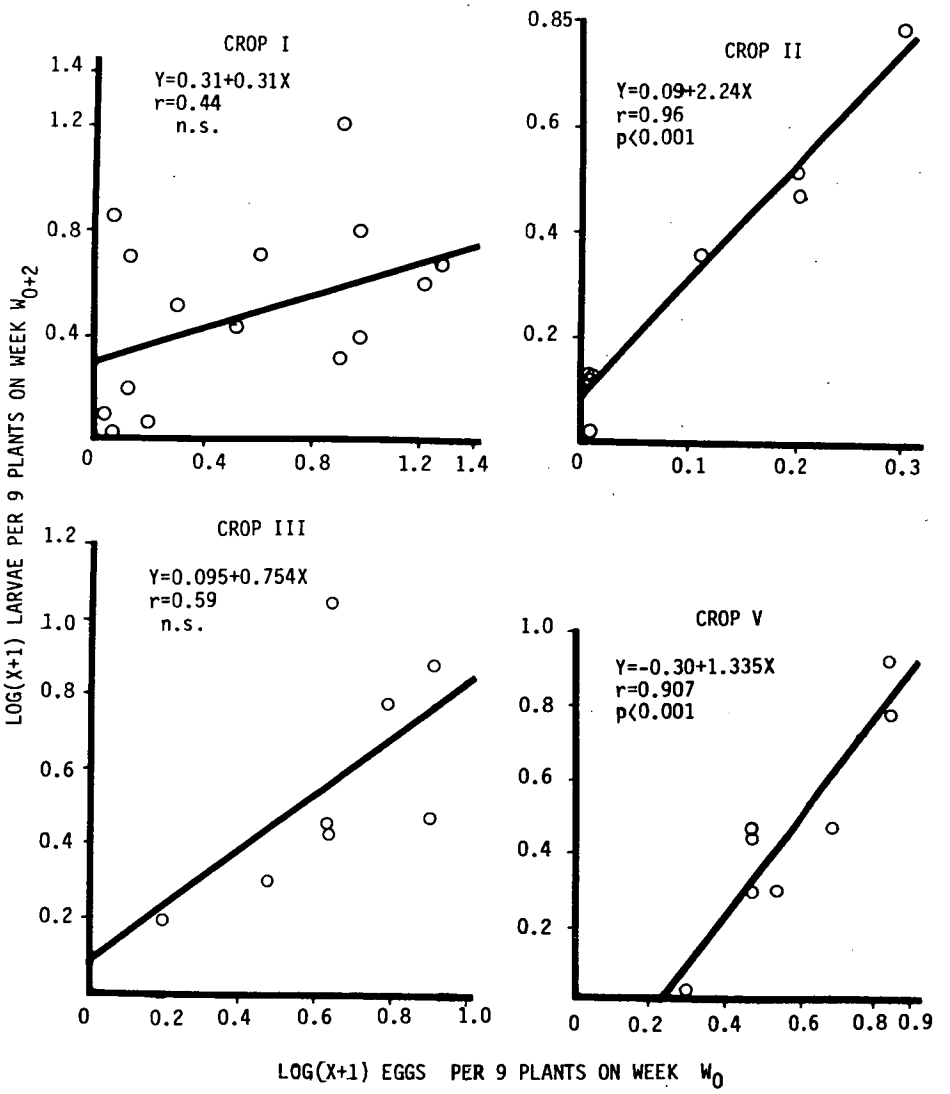



Fig. 4.12. Relationship between CWB eggs and larval (all instars) populations in cabbage crops at S.J.F. College (1982-85).

Table 4.5 Matrix of correlation (r) of cabbage white butterfly (CWB) egg and larval abundance to key environmental variables at S.J.F. College (1982-85).

| Crop No. | Period (Season) | CWB Stage | Simple correlation+ T | R.H. | Rf | Multiple correlation T,R.H.,Rf | T,R.H. | T,Rf |
|---|---|---|---|---|---|---|---|---|
| | | | | | | ** | ** | |
| 1 | Sept.82-Feb.83 | Egg | -.319 | -.265 | -.009 | .612 | .599 | .358 |
| | (Spring-Summer) | Larval | -.013 | .141 | .355 | .381 | .143 | .355 |
| | | | | | | | *** | ** |
| 2 | Mar.83-Sept.83 | Egg | .937 | -.590 | .688 | ... | .999 | .991 |
| | (Autumn-Spring) | Larval | .371 | -.449 | -.006 | .502 | .496 | .383 |
| | | | | | | * | | |
| 3 | Nov.83-Mar.84 | Egg | .001 | -.582 | -.440 | .740 | .646 | .454 |
| | (Summer-Autumn) | Larval | .640 | -.116 | -.113 | .686 | .685 | .663 |
| 5 | Oct.84-Mar.85 | Egg | -.598 | -.600 | -.330 | .631 | .630 | .555 |
| | (Spring-Autumn) | Larval | -.530 | -.225 | .190 | .621 | .620 | .566 |

+ : Abreviated as T: Temperature, R.H : Relative humidity, Rf : Rainfall
* = P < 0.05
** = P < .01
*** = P < .001 based upon only 4 records in March-April and could be misleading, for the whole season.
... = Records not enough for multiple correlation.

variables and the population levels of both egg and larvae of this butterfly. No single variable had a significant correlation with either egg or larval population levels. However, the combined effect of these variables was predominantly promotory in nature in crops I, II and III for egg population and in crop III for larval population. In other crops, a positive correlation of varying degree was obtained between the weather variables and the larval abundance.

The relatively higher temperature experienced during crops I and V had a negative but non-significant correlation with egg population whereas relative humidity (except in crop I) had a negative correlation with both egg and larval populations .

Figure 4.13 shows the influence of T/H and Tm/R on CWB egg population levels. Except for crop III, no significant correlation was obtained in any crop. Negative and non-significant correlations in crops I and V reflected the individual correlation of temperature with the egg populations (Table 4.5). The optimum ranges of T/H and Tm/R corresponding to egg population maxima were 0.18-0.25 and 1.8-4.5 respectively. An exceptional value of Tm/R (10-14) coincided with maximal egg population in crop III. None of the larval populations in any season showed significant correlation with T/H or Tm/R indices (Fig. 4.14). However, the optimum ranges of T/H and Tm/R indices relating to the larval population peaks were 0.18-0.26 and 1.4-4 respectively.

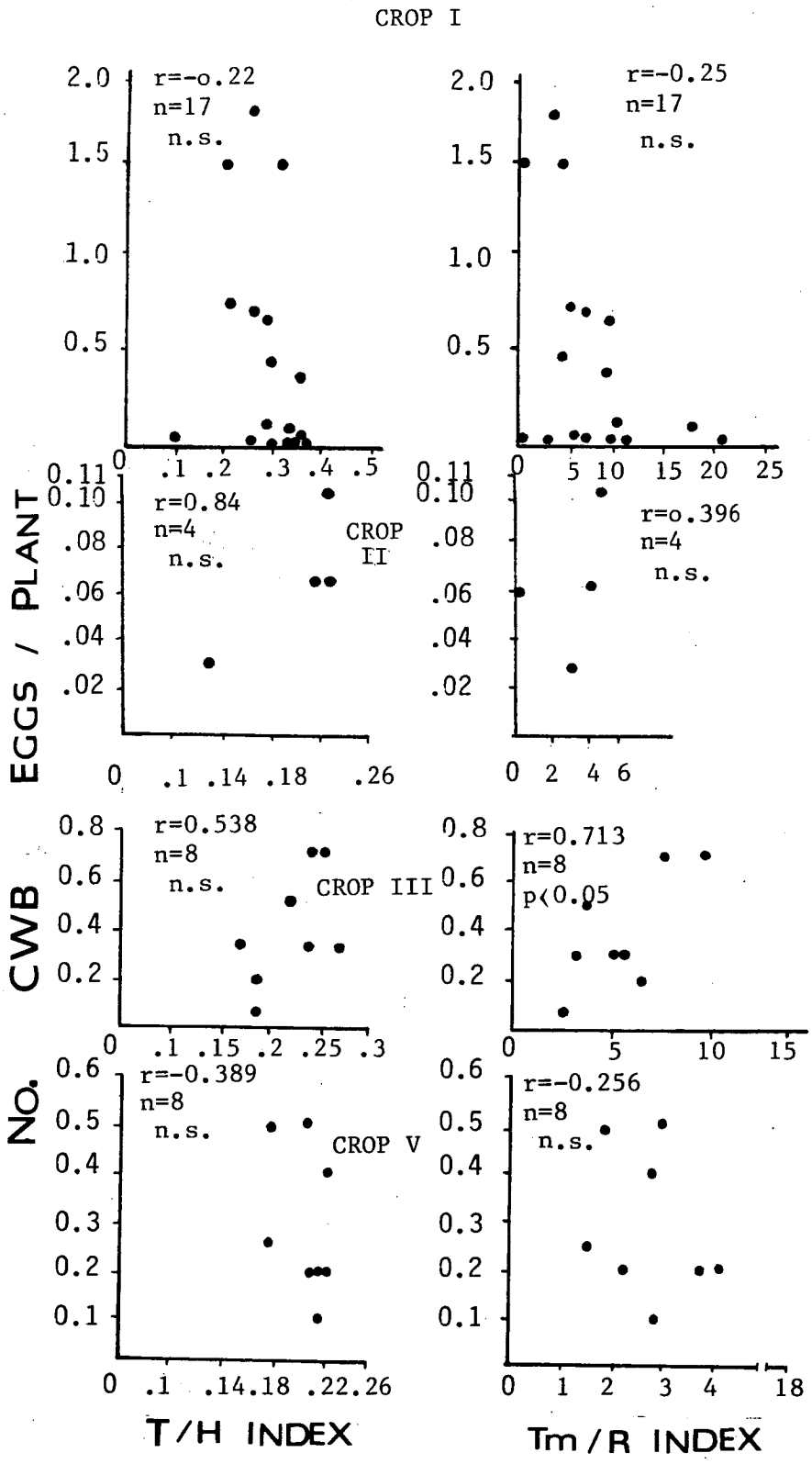



Fig. 4.13. Egg populations of CWB plotted against temperature-humidity (T/H) and temperature-rainfall (Tm/R) indeces at S.J.F. College plots (1982-85).

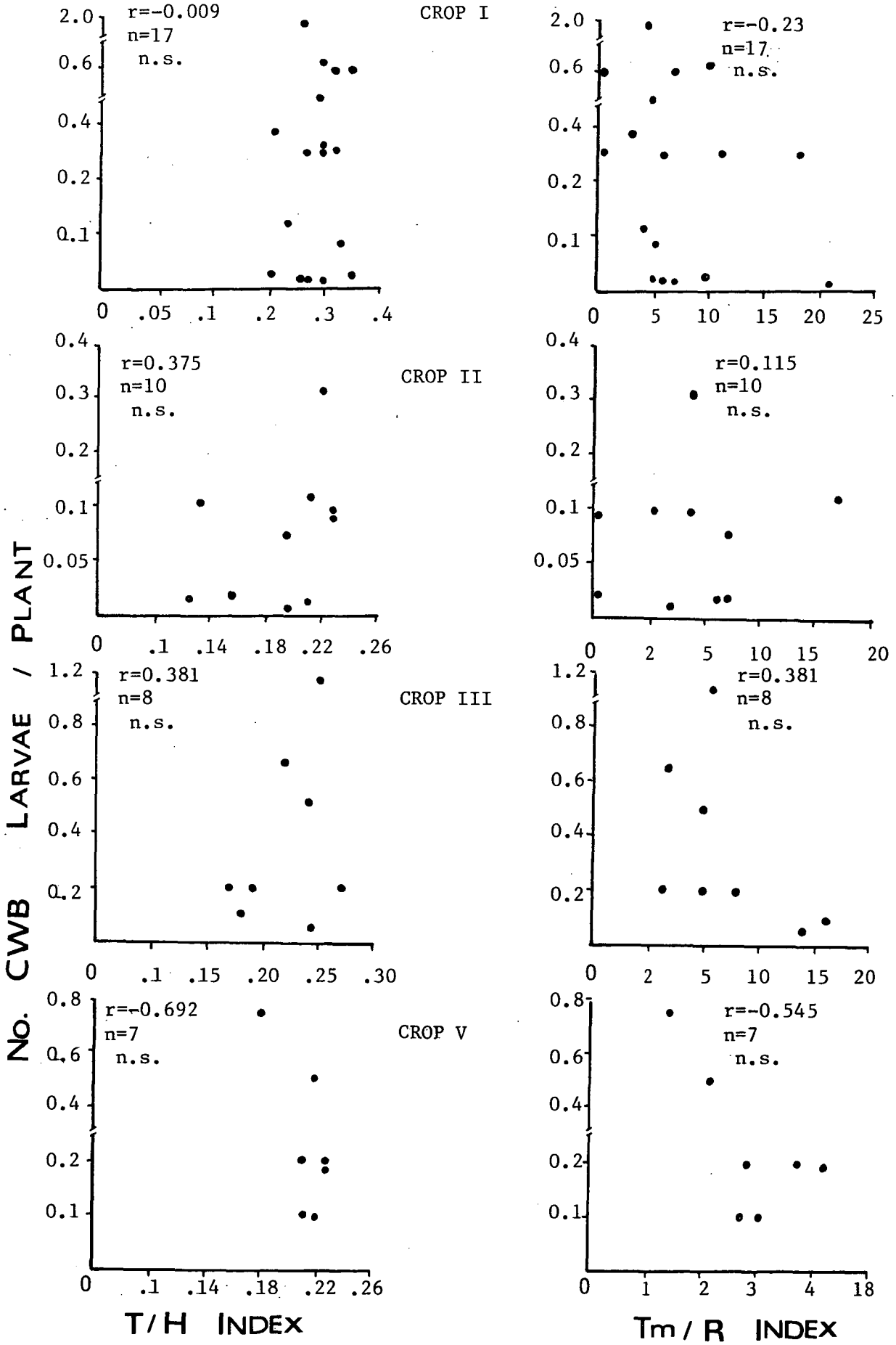



Fig. 4.14. Larval population of CWB plotted against temperature-humidity (T/H) and temperature-rainfall (Tm/R) indices at S.J.F. College plots (1982-85).

4.3.2.3 Diamondback moth

Seasonal abundance of larval and pupal populations are represented in Fig. 4.8. This species was most abundant between late spring and late summer, however, an autumn population was also recorded in crop II. Oviposition commenced in early October (crop I) and larvae were first recorded in mid October. Although a marked fluctuation in larval populations was observed between different crops, maximum levels of both larvae and pupae were recorded during mid November - mid January. Populations fluctuated from 1-2.2 larvae and 0.5-0.8 pupae per plant. Both larval and pupal populations declined from 3rd week of May until September in crop II and May-October in crop V. There was a general decline in the populations as the cabbage crop reached the heading stage.

As expected pupal populations were related to larval populations. Relationships between larval and pupal population levels recorded in different crops are illustrated in Fig. 4.15. Comparison of the two populations from all 4 crops gave positive correlation of varying degree (r=0.53-0.93), however comparatively, lower pupal densities suggested the presence of one or more mortality factors.

Table 4.6 shows the relationships between weather variables and the population abundance of larvae and pupae. No variable was found to be influential on either larval or pupal populations of this species. However, the combined effect of temperature, relative humidity or temperature, relative humidity and rainfall presented

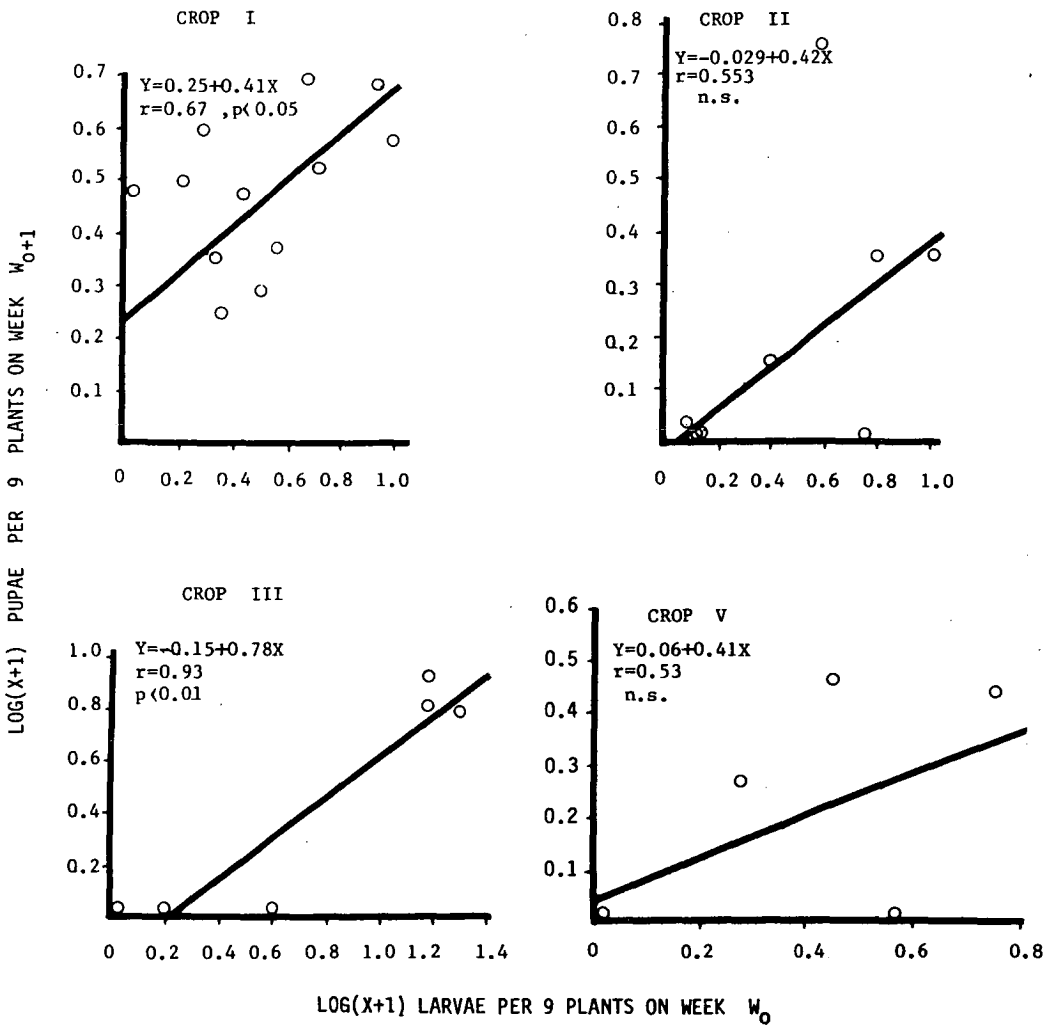



Fig.4.15. Relationship between DM larval and pupal populations in cabbage crops at S.J.F. College plots (1982-85).

Table 4.6 Matrix of correlation (r) of diamondback moth (DM) larval and pupal abundance to key environmental variables at S.J.F. College (1982-85).

| Crop No. | Period (Season) | DM Stage | Simple correlation[+] T | R.H. | Rf | Multiple correlation T,R.H.,Rf | T,R.H. | T,Rf |
|---|---|---|---|---|---|---|---|---|
| 1 | Sept.82-Feb.83 | Larval | .231 | -.029 | .390 | .406 | .234 | .401 |
| | (Spring-Summer) | Pupal | .081 | -.388 | .282 | .437 | .388 | .284 |
| 2 | Mar.83-Sept.83 | Larval | -.079 | -.697 | .161 | .763* | .737* | .189 |
| | (Autumn-Spring) | Pupal | .507 | .504 | -.271 | .763 | .761 | .510 |
| 3 | Nov.83-Mar.84 | Larval | .396 | -.696 | -.417 | .725* | .699 | .459 |
| | (Summer-Autumn) | Pupal | .251 | -.121 | .086 | ... | .435 | .568 |
| 5 | Oct.84-Mar.85 | Larval | .490 | -.290 | .771 | ... | .565 | .952* |
| | (Spring-Autumn) | Pupal | .524 | .539 | .486 | ... | ... | ... |

+ : Abbreviated as T : Temperature, R.H : Relative humidity, Rf : Rainfall
* = P < 0.05 ; ... Records not enough for multiple correlation.

significant ($P<0.05$) correlations with both larval and pupal population in crop II and larval population in crop III. A significant correlation was found between the combined influence of temperature and rainfall and the larval population in crop V.

Relative humidity alone had a generally negative correlation with both larval and pupal populations. Moreover, no significant correlation was obtained between rainfall and larval or pupal population levels. Figure 4.16 shows the influence of T/H and Tm/R indices on the larval populations. No significant correlation was obtained between any index and larval population in any crop. T/H indices had weak to strong positive correlations ($r=0.153$ in winter crop and 0.41, 0.677 and 0.763 in crop I, III, V respectively) with the larval populations which was a suggestive of warm and dry weather condition being favourable for larval increases. The optimum ranges of T/H and Tm/R indices corresponding to larval population maxima were found to be 0.22-0.35 and 2.2-10.0 respectively. Figure 4.17 represents the relationship of T/H and Tm/R indices to the pupal populations. No significant correlation was obtained between T/H indices and corresponding pupal populations. Similarly, correlations between Tm/R indices and pupal populations were not significant except in crop II ($r=0.855$ $P<0.05$).

The summary of T/H and Tm/R ranges compatible to population maxima of all 3 insect pests is illustrated in Fig. 4.18.

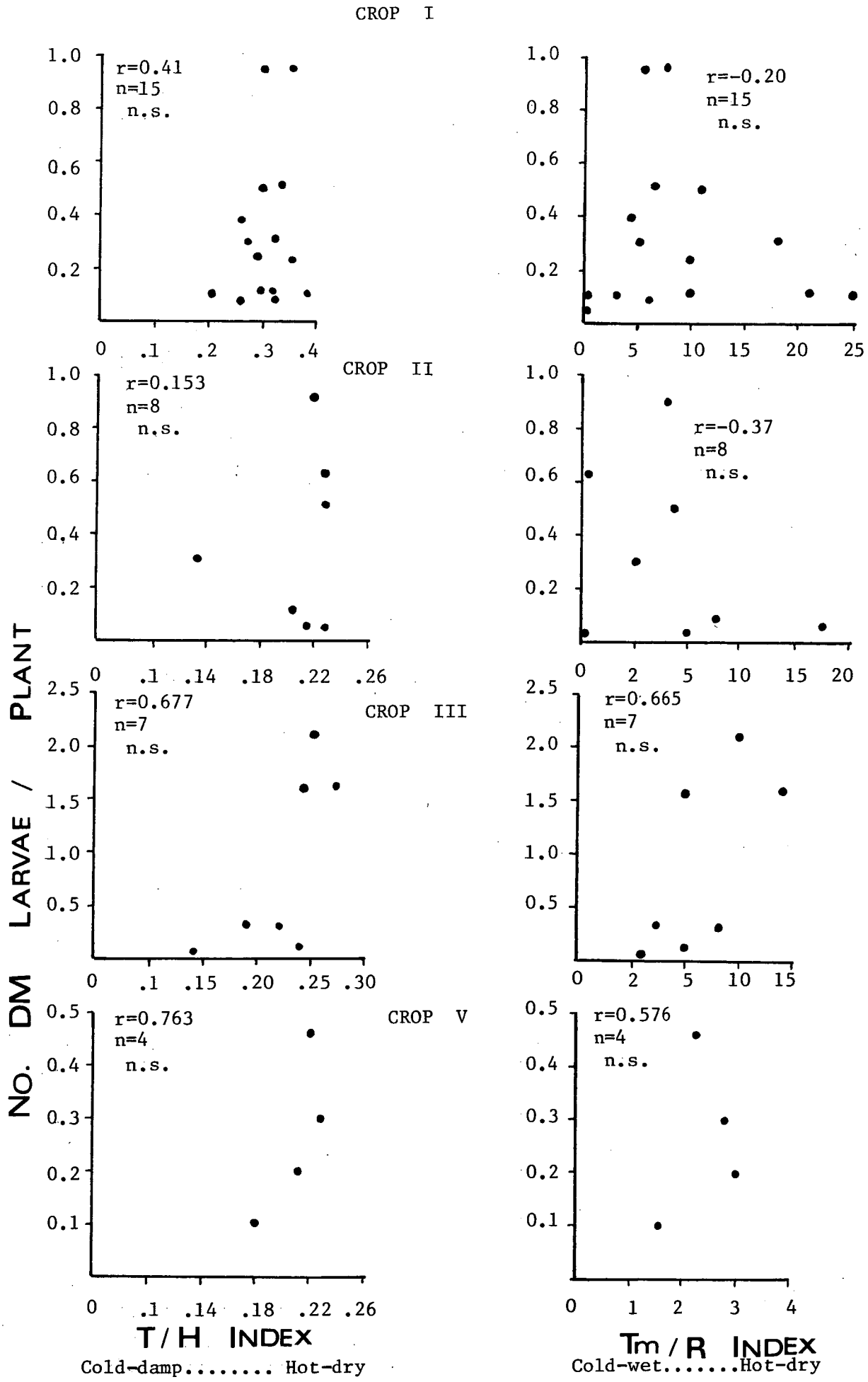



Fig. 4.16. DM larval populations plotted against temperature-humidity (T/H) and temperature-rainfall (Tm/R) indices at S.J.F. College plots (1982-85).

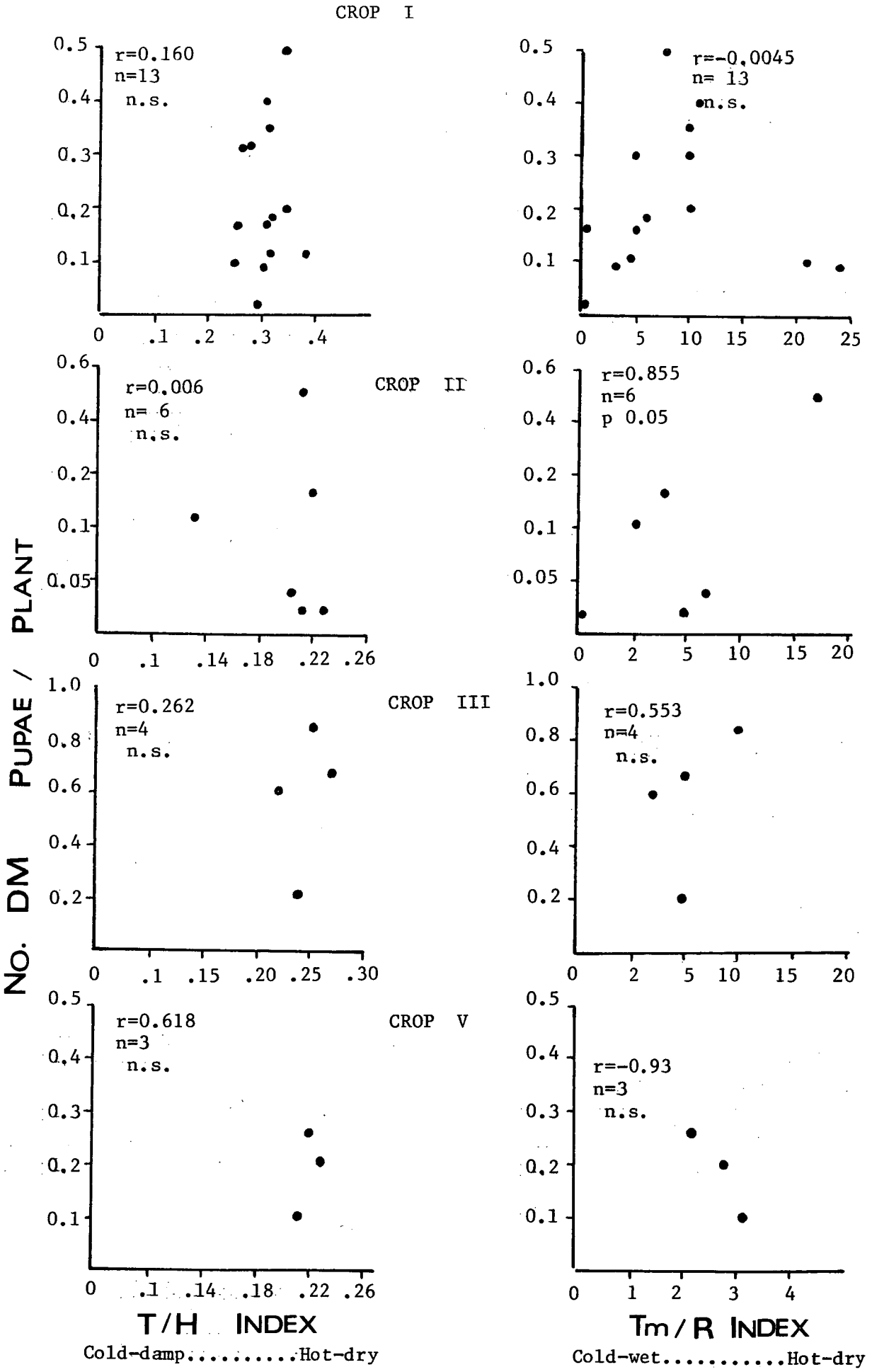



Fig. 4.17. DM pupal population plotted against temperature-humidity (T/H) and temperature-rainfall (Tm/R) indices at S.J.F. College plots (1982-85).

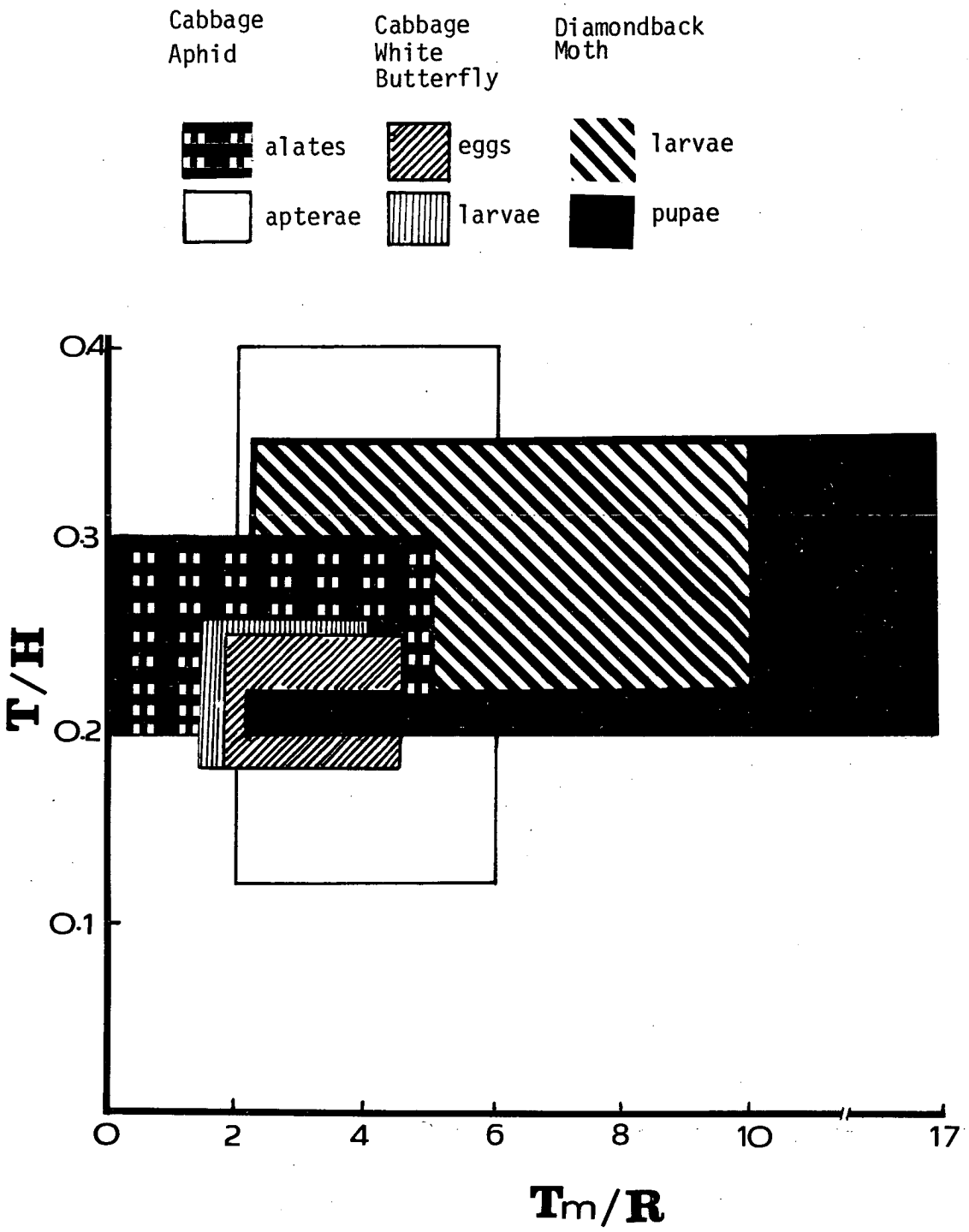



Fig. 4.18. The optimum ranges of temperature-humidity (T/H) and temperature-rainfall (Tm/R) indices relative to the population maxima of different stages of insect pests on cabbage plants at S.J.F. College plots (1982-85).

### 4.3.3 Seasonal abundance of pests, natural enemies and the efficiency of different sampling methods

Data on the seasonal abundance of pest populations on the host plant monitored by direct documentation has been furnished in the previous pages. However, to monitor the activity of more mobile forms like alate CA, adult DM and associated parasitoids and predators, trapping devices were employed. The purpose of this section is to compare different trapping devices for their efficiency to sample the abundance and dispersal activities of subject insect species and their reliability, consistency, cost effectiveness and efficiency compared with the direct counting method. The maximum catch of each species of insect was considered separately for each device and regarded as a function of the reliability of trapping device relative to the temporal prevalence of the insect.

#### 4.3.3.1 Sticky traps

The key species monitored by sticky traps were as follows:

(i) Alate CA;
(ii) Primary parasitoid of CA, D. rapae;
(iii) Hyperparasitoid of CA, A. brassicae;
(iv) Adult DM;
(v) Larval parasitoid of CWB, A. glomeratus;
(vi) Pupal parasitoid of CWB, P. puparum;
(vii) Larval parasitoid of DM, Diadegma rapi, D. eucerophaga, A. plutellae;
(viii) Pupal parasitoid of DM, Thyraeella collaris;

The potential predatory insect species caught by sticky traps were :

(i) Brown lace-wing, Micromus tasmaniae;
(ii) Adult syrphid, Melangyna viridiceps;
(iii) Adult coccinellids, Coccinella repanda, Leis conformis.

Figures 4.19-4.21 show the prominent catches of the key species and potential predators on the sticky traps. Very few cabbage aphid alates were caught by this trapping method and their trends were not compatible to those recorded by direct counts on the host plants. These results suggested that sticky traps were not an efficient device for population sampling of alate aphids.

Appreciable numbers of the primary parasitoid of CA, D. rapae were caught consistently in all crops. Maximum catches (10-12.5 wasps/trap) were obtained during December-February. The trends in the numbers of the parasitoids caught were not consistent with those found on the plants in crops I and II, however, these trends were fairly compatible in crop III and V.

The hyperparasitoid of CA, A. brassicae, was common with marked numbers (maximum 3.5 wasps/trap) in crop I. In other crops their population on both plants and sticky traps were very low. However, catches on sticky traps were less (crops II, III) to more (crop V) consistent with those recorded on host plants.

Very few adult DM were caught on the traps and the numbers or trends were not compatible to their larval

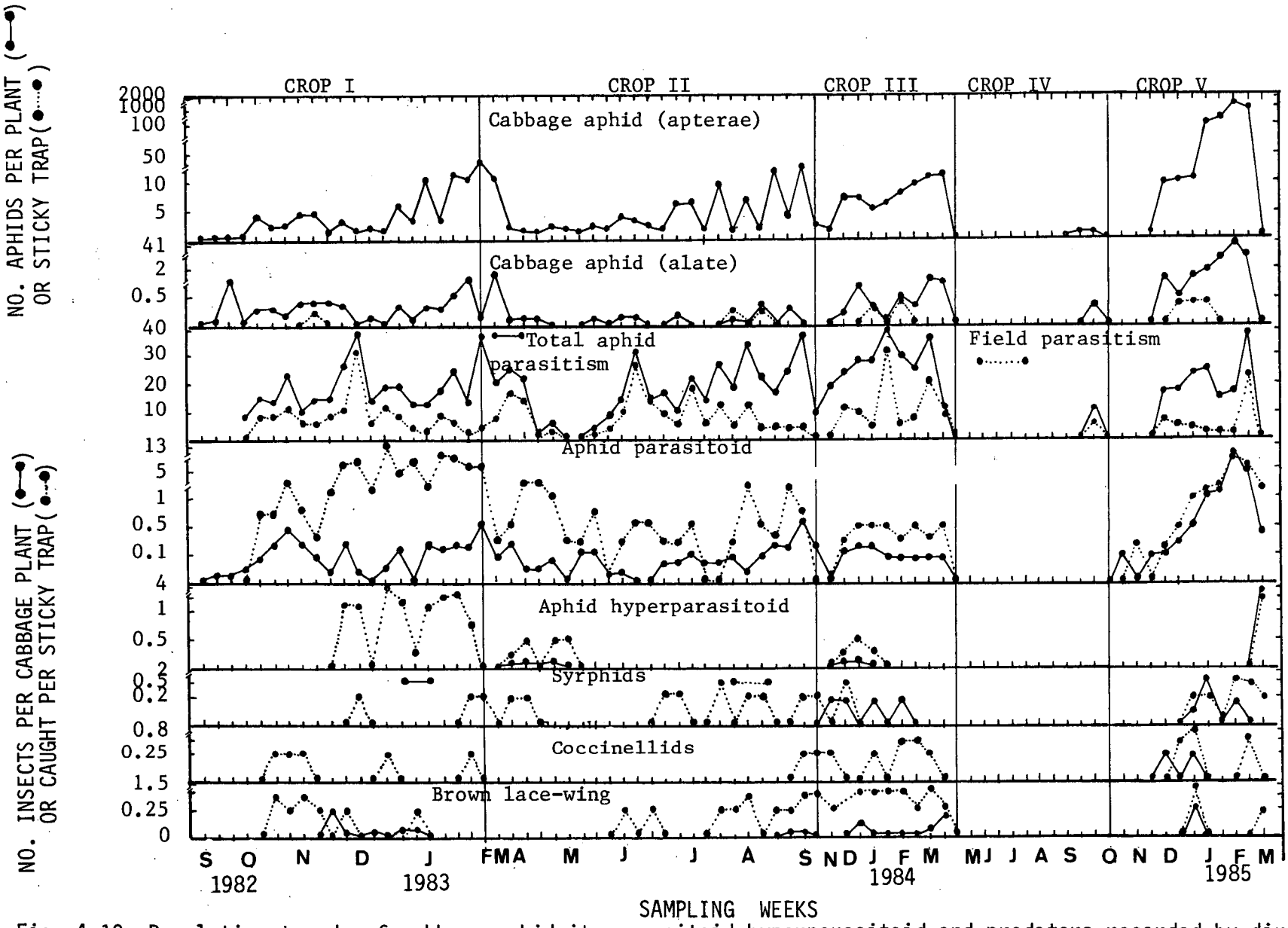



Fig. 4.19. Population trends of cabbage aphid,its parasitoid,hyperparasitoid and predators recorded by direct counts and sticky traps in cabbage plots at S.J.F. College (1982-85).

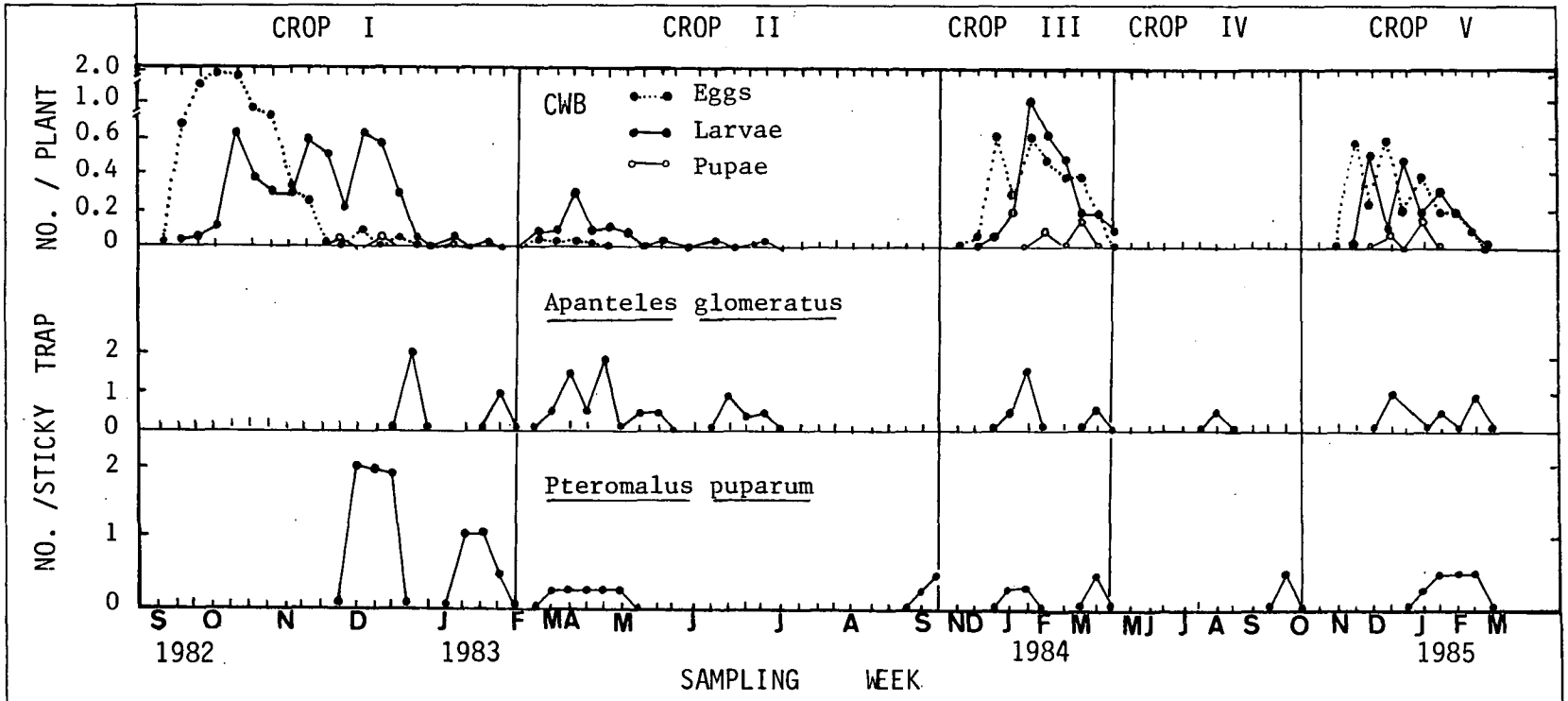



Fig. 4.20. Population trends of cabbage white butterfly (CWB), its larval parasitoid, Apanteles glomeratus and pupal parasitoid, Pteromalus puparum at S.J.F. College plot (1982-85).

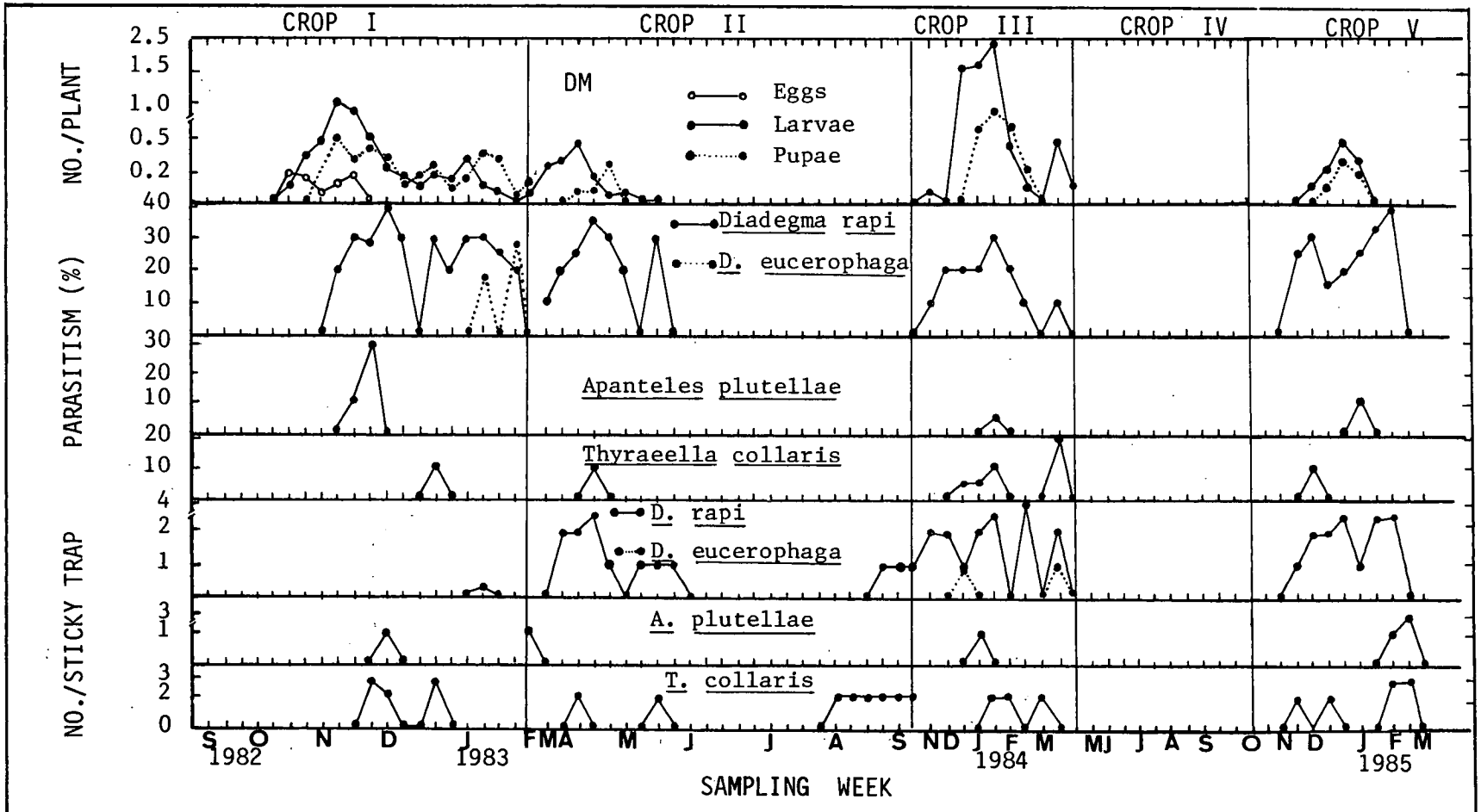



Fig. 4.21. Population trends of diamondback moth (DM) on cabbage plants and its parasitism by parasitoids reared and recorded on sticky traps.

population recorded on the host plants.

Sticky traps proved to be an efficient method for monitoring the activity of the CWB parasitoids, A. glomeratus and P. puparum. Both parasitoids were caught in all crops and their peaks coincided with their host population peaks in crops II, III and V. A. glomeratus was first caught in mid December (crop I) but later disappeared until mid January. In the second crop, it was active in April and persisted until mid May. Small peaks were also observed during June. Variable catches in crops III, IV and V showed its activity from December-mid February. Despite its apparent lack of synchronization with the first larval generation early in the season it did coincide with the 2nd (crops III and V) or 3rd (crop I) generation of its larval hosts (Fig. 4.20). P. puparum was usually trapped later in the season particularly from December-early March (crop I-II). The highest catches were obtained in the crop I where a maximum 2 wasps per trap were caught.

Sticky traps were also efficient in catching both larval and pupal parasitoids of DM. Although the catches were not consistent between different crops, the number of individual species trapped indicated that the activities of the parasitoids could be monitored with sticky traps. The larval parasitoid of DM, D. rapi, was the most abundant species and its peak catches were fairly compatible to its larval host population in crop II, III and V. Relatively smaller numbers of A. plutellae and T. collaris were caught by the sticky traps.

D. rapi was first caught in January (crop I), disappeared during February-March and reappeared in April (crop II) remaining active until the last week of May. It was absent again during the colder months and appeared in late August and persisted with variable peaks until mid March (crop III). The maximum catches (4 wasps/trap) of this parasitoid were made in late February (crop III). D. eucerophaga and A. plutellae were not sufficient to provide information on their seasonal abundance. However, their activities were recorded in December-late February. Variable peaks of T. collaris catches did not coincide with its pupal host populations on cabbage plants. This parasitoid was first caught in late November (crop I). Low catches were also made from late July-September (crop II).

Sticky traps were also efficient in catching potential predators and trends in their numbers are shown in Fig. 4.19. These trends, however, were not consistent with those recorded on cabbage plants. Generally, larger numbers of the predators (adult) were caught by the sticky traps than observed on plants (both larvae and adults). However, the sticky trap catches of predators were not consistent with the population trends of CA.

#### 4.3.3.2 Modified Moericke traps

This sampling device was employed to sample the following key and general species.

Key species :

(i) Alate CA;
(ii) Primary parasitoid of CA, D. rapae;
(iii) Larval and pupal parasitoids of CWB;
(iv) Larval and pupal parasitoids of DM;

General species :

(i) Ants;
(ii) Spiders;
(iii) Brown lace-wing;
(iv) Syrphids;
(v) Coccinellids.

The trends in numbers of individual key and general species, caught in Moericke traps, in relation to those recorded on cabbage plants are shown in Fig. 4.22. For the sake of analytical comparisons weekly catches of each group of arthropods were totalled for each month and are presented in Tables 4.7, 4.8. Cabbage aphid alates were caught in sufficient numbers in almost all seasons except the months of April-June in crop II and May-June and September-October in crop IV. Catches were markedly consistent with the aphid (alate and apterae) populations on cabbage plants which indicated the reliability and efficiency of this sampling procedure. Aphid catches were about 11 and 66% of the total arthropods caught in crop I-II and III-V respectively (Tables 4.7, 4.8). With exception to crop II the alate aphid catches were positively correlated with recorded alate numbers on the cabbage plants (Table 4.9).

The primary parasitoid of CA, D. rapae, was caught consistently in these traps. However, no catches were obtained during colder months in crop II. The parasitoid

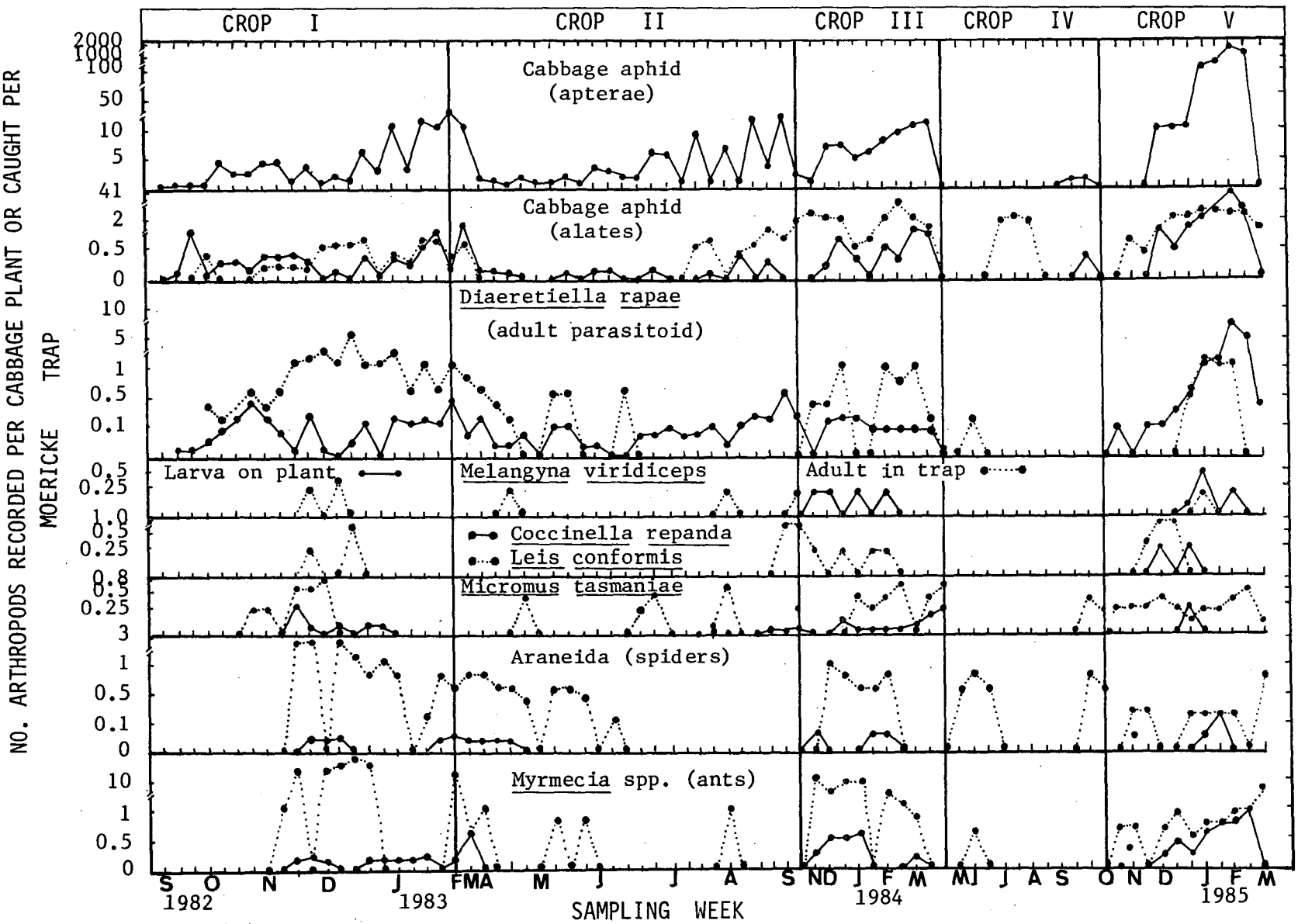



Fig. 4.22. Population trends of cabbage aphid, its parasitoids and predators recorded by direct counts on cabbage plants (•——•) and modified Moericke traps (•·····•) at S.J.F.College plots (1982-85).

Table 4.7 Composition and incidence of arthropods caught in modified Moericke traps in the cabbage plots at S.J.F. College (1982-83).

| Taxon / Species | Monthly total catch per 5 traps | | | | | | | | | | | | $\bar{X}$ | @ S.D. | % of Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Crop I | | | | | Crop II | | | | | | | | | |
| | O | N | D | J | F | M | A | M | J | J | A | S | | | |
| Myrmecia spp.* | - | 23 | 101 | - | 11 | 1 | 3 | 2 | - | - | 3 | - | 12.0 | 28.8 | 20.05 |
| Diaeretiella rapae ** | 8 | 23 | 69 | 9 | 6 | 13 | 6 | 6 | 3 | - | - | - | 11.9 | 19.1 | 19.88 |
| Myzus persicae | 23 | 52 | 27 | - | - | 2 | 2 | - | 11 | - | - | - | 9.75 | 16.3 | 16.30 |
| Macrosiphum euphorbiae | 31 | 40 | 26 | - | - | - | - | - | - | - | - | - | 8.08 | 14.9 | 13.50 |
| Araneida * + | - | 26 | 31 | 5 | 3 | 4 | 12 | 8 | 1 | - | - | - | 7.5 | 10.5 | 12.53 |
| Brevicoryne brassicae ** | 2 | 4 | 14 | 12 | 4 | 3 | - | - | - | 7 | 12 | 19 | 6.4 | 6.35 | 10.70 |
| Micromus tasmaniae * | 1 | 1 | 12 | - | - | - | 2 | - | 3 | - | 3 | 1 | 1.9 | 3.3 | 3.17 |
| Coccinella repanda * | - | 1 | 2 | - | - | - | - | - | - | - | - | 6 | 0.75 | 1.76 | 1.25 |
| Diadegma rapi ** | - | - | - | 1 | - | - | 2 | - | - | - | 1 | 1 | 0.41 | 0.66 | 0.68 |
| Melangyna viridiceps * | - | 1 | 2 | - | - | - | 1 | - | - | - | - | 1 | 0.41 | 0.66 | 0.68 |
| Eulophidae | - | 4 | - | - | - | - | - | - | - | - | - | - | 0.33 | 1.15 | 0.55 |
| Carabidae * | - | 1 | - | - | - | - | - | - | - | - | 1 | - | 0.16 | 0.38 | 0.26 |
| Isopoda ++ | - | - | 2 | - | - | - | - | - | - | - | - | - | 0.16 | 0.57 | 0.26 |
| Tachinidae | - | - | - | - | - | - | - | - | - | - | 1 | - | 0.08 | 0.28 | 0.13 |
| Total | 65 | 176 | 286 | 27 | 24 | 23 | 28 | 16 | 18 | 7 | 21 | 28 | 59.84 | - | 100 |

@ Standard deviation of monthly totals, **=Key species , *=General predators

+ Araneida : Dipluridae : Aname pexa
Dysderidae : Dysdera crocata
Clubionidae: Clubiona elaphines
Chiracanthium stratioticum (Ref : Hickman, 1967)

++ Isopoda : Styloniscidae : Styloniscus maculosus (Ref: Green, 1961)

Table 4.8 Composition and incidence of arthropods caught in modified Moericke traps in the cabbage plots at S.J.F. College (1983-85).

| Taxon / Species | Monthly total catch per 5 traps | | | | | | | | | | | | | | | | | $\bar{X}$ | SD | % of Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Crop III | | | | | Crop IV | | | | | | Crop V@ | | | | | | | | |
| | N | D | J | F | M | M | J | J | A | S | O | N | D | J | F | M | | | | |
| Brevicoryne brassicae ** | 20 | 20 | 7 | 110 | 19 | 0 | 0 | 20 | 10 | 0 | 0 | 4 | 24 | 40 | 94 | 4 | | 23.25 | 32.86 | 66.44 |
| Myrmecia spp * | 10 | 9 | 5 | 7 | 2 | 0 | 1 | 0 | 0 | 0 | 1 | 1 | 6 | 4 | 5 | 4 | | 3.40 | 3.32 | 9.71 |
| Araneida * | 0 | 9 | 6 | 4 | 0 | 3 | 7 | 0 | 0 | 4 | 3 | 1 | 1 | 2 | 1 | 4 | | 2.80 | 2.73 | 8.00 |
| Diaeretiella rapae ** | 2 | 7 | 0 | 9 | 6 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 3 | 10 | 5 | 0 | | 2.68 | 3.55 | 7.65 |
| Micromus tasmaniae * | 0 | 0 | 3 | 5 | 5 | 0 | 0 | 0 | 0 | 2 | 2 | 2 | 3 | 3.5 | 4 | 1 | | 1.90 | 1.84 | 5.43 |
| Coccinella repanda * | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1.5 | 8 | 0 | 0 | 0 | | 0.72 | 1.9 | 2.05 |
| Leis conformis * | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | 0.12 | 0.34 | 0.34 |
| Melangyna viridiceps * | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | | 0.12 | 0.34 | 0.34 |
| Total | 33 | 46 | 22 | 136 | 33 | 3 | 9 | 20 | 10 | 6 | 6 | 9.5 | 45 | 60.5 | 109 | 13 | | 34.99 | - | 100 |

** : Key species
* : General predators
SD : Standard deviation of monthly totals

catches were about 19.9 and 7.7% of the total arthropods caught during crops I-II and III-V respectively. Very few larval and pupal parasitoids of CWB and DM were caught with this trapping method and did not have any consistency with their host numbers on cabbage plants.

Ants were caught in largest numbers (20%) during crop I and II however, they ranked second to CA in crop III-V comprising of 9.7% of the total catches of arthropods. Their numbers peaked in November-December with none to very low activity during colder months. Their populations appeared to be seriously disturbed by the successive cultivations performed before each transplanting of a new crop. Much higher numbers were caught by the traps than were actually recorded on the cabbage plants. However, there was no correlation between the ant catches and aphid population levels on cabbage plants (Table 4.10).

Spiders accounted for 12.5 and 8% of the total arthropod catches in crops I-II and III-V respectively. Although they were recorded occasionally on cabbage plants, higher trends in numbers were obtained by this sampling procedure. No significant correlation was found between the spider catches and the aphid population on the plants (Table 4.10).

The brown lace-wing, M. tasmaniae, was also attracted to these traps and higher levels were caught in the traps than those actually observed on plants. This species accounted for almost 3-5% of the total arthropods caught in the traps. These traps were more efficient than sticky traps in sampling the abundance of M. tasmaniae. However,

Table 4.9 Relationship between mean alate cabbage aphid population levels monitored by direct counts on plants (X) and in modified Moericke traps (Y).

| Crop No. | Season | X-variable | Y-variable | Regression equation | n | r | p |
|---|---|---|---|---|---|---|---|
| I | Spring-Summer | Alate per plant | Alate per trap | Y=0.316+0.39X | 15 | 0.29 | N.S. |
| II | Autumn-Spring | Alate per plant | Alate per trap | Y=0.54 -0.004X | 16 | -0.18 | N.S. |
| III | Summer-Autumn | Alate per plant | Alate per trap | Y=-0.32+10.5X | 10 | 0.49 | N.S. |
| V | Spring-Autumn | Alate per plant | Alate per trap | Y=1.186+0.165X | 8 | 0.877 | <.01 |

N.S. = not significant ($p > 0.05$)

Table 4.10 Relationship between cabbage aphid populations on cabbage plants and general predators caught in modified Moericke traps (1982-83).

| X-variable | Y-variable | Regression equation | n | r | p |
|---|---|---|---|---|---|
| Apterae per 9 plants | Brown lace wings per 5 traps | Y=5.62+0.094X | 13 | 0.02 | N.S. |
| Apterae per 9 plants | Ants per 5 traps | Y=5.89-0.0X | 10 | -0.08 | N.S. |
| Apterae per 9 plants | Spiders per 5 traps | Y=4.95-0.183X | 14 | -0.21 | N.S. |

N.S. = not significant ($p > 0.05$)

the catches of this species were not significantly correlated with aphid population levels (Table 4.10).

Variable numbers of M. viridiceps, C. repanda and L. conformis were also caught in the traps but the trends were less consistent than those obtained in sticky traps.

4.3.3.3 Pitfall traps

Table 4.11 shows the abundance of the arthropods captured in pitfall traps during crop I and II. Ants were the most abundantly trapped fauna (almost 50%) in crop I. However, in crop II ants rated second (20.3%) to spiders (48%). Ants and spiders together comprised 71.9% and 68.3% of the total arthropods collected during crop I and II respectively.

In crop I, other abundant arthropods were Acarina (7.5%), Isopods (5.5%), Chilopods (3.3%) and Braconidae (2.6%). Coleopterous predators were relatively more abundant in crop I than in crop II. In the former crop, they consisted of Carabids (1.4%), Staphylinids (1.3%) and Coccinellids (0.5%). Carabids were also recorded in crop II (0.6%) but Coccinellids and Staphylinids were absent in this crop.

Figure 4.23 shows that the captures of most groups and individual maxima occured in spring and summer and with the exception of spiders and ants, numbers tended to decline with the onset of autumn and winter. Weekly catches of some groups (Braconidae, Chalcididae, Mantidae and Chrysopidae) were too small to allow interpretations of their dynamics. No significant correlations were

Table 4.11 Seasonal totals of predaceous and parasitic arthropods captured in pitfall traps in untreated cabbage plots at S.J.F. College (1982-83).

| Taxon | Crop I Sep. 82-Feb. 83 | | | Crop II Mar. 83-Aug. 83 | | |
|---|---|---|---|---|---|---|
| | Weekly Capture $\bar{X}$ | + S.D. | % Of Total Capture | Weekly Capture $\bar{X}$ | + S.D. | % Of Total Capture |
| Carabidae | 0.76 | 1.7 | 1.44 | 0.05 | 0.22 | 0.60 |
| Coccinellidae | 0.29 | 0.68 | 0.55 | - | - | - |
| Staphylinidae | 0.70 | 1.04 | 1.33 | - | - | - |
| Braconidae | 1.41 | 4.0 | 2.68 | - | - | - |
| Chalcididae | 0.70 | 1.8 | 1.33 | 0.05 | 0.22 | 0.60 |
| Formicidae | 26.41 | 23.66 | 50.34 | 1.70 | 2.90 | 20.38 |
| Ichneumonidae | 0.29 | 0.84 | 0.55 | 0.31 | 0.82 | 3.71 |
| Vespidae | 0.76 | 1.85 | 1.45 | - | - | - |
| Reduvidae | - | - | - | 0.05 | 0.22 | 0.60 |
| Mantidae | - | - | - | 0.05 | 0.22 | 0.60 |
| Chrysopidae | 0.05 | 0.24 | 0.09 | - | - | - |
| Hemerobeidae | 0.17 | 0.52 | 0.32 | 0.05 | 0.22 | 0.60 |
| Acarina (Anistidae) | 4.0 | 4.92 | 7.62 | - | - | - |
| Araneida | 11.64 | 11.4 | 22.18 | 4.15 | 3.73 | 49.76 |
| Chilopoda | 1.76 | 2.35 | 3.35 | 1.52 | 1.92 | 18.22 |
| Diplopoda | 0.29 | 0.84 | 0.55 | 0.15 | 0.68 | 1.79 |
| Isopoda | 3.0 | 2.90 | 5.71 | - | - | - |
| Scorpionida | 0.23 | 0.75 | 0.43 | 0.26 | 0.56 | 3.11 |
| Total | 52.46 | | 100 | 8.34 | | 100 |

+ Standarad deviation of weekly captures.

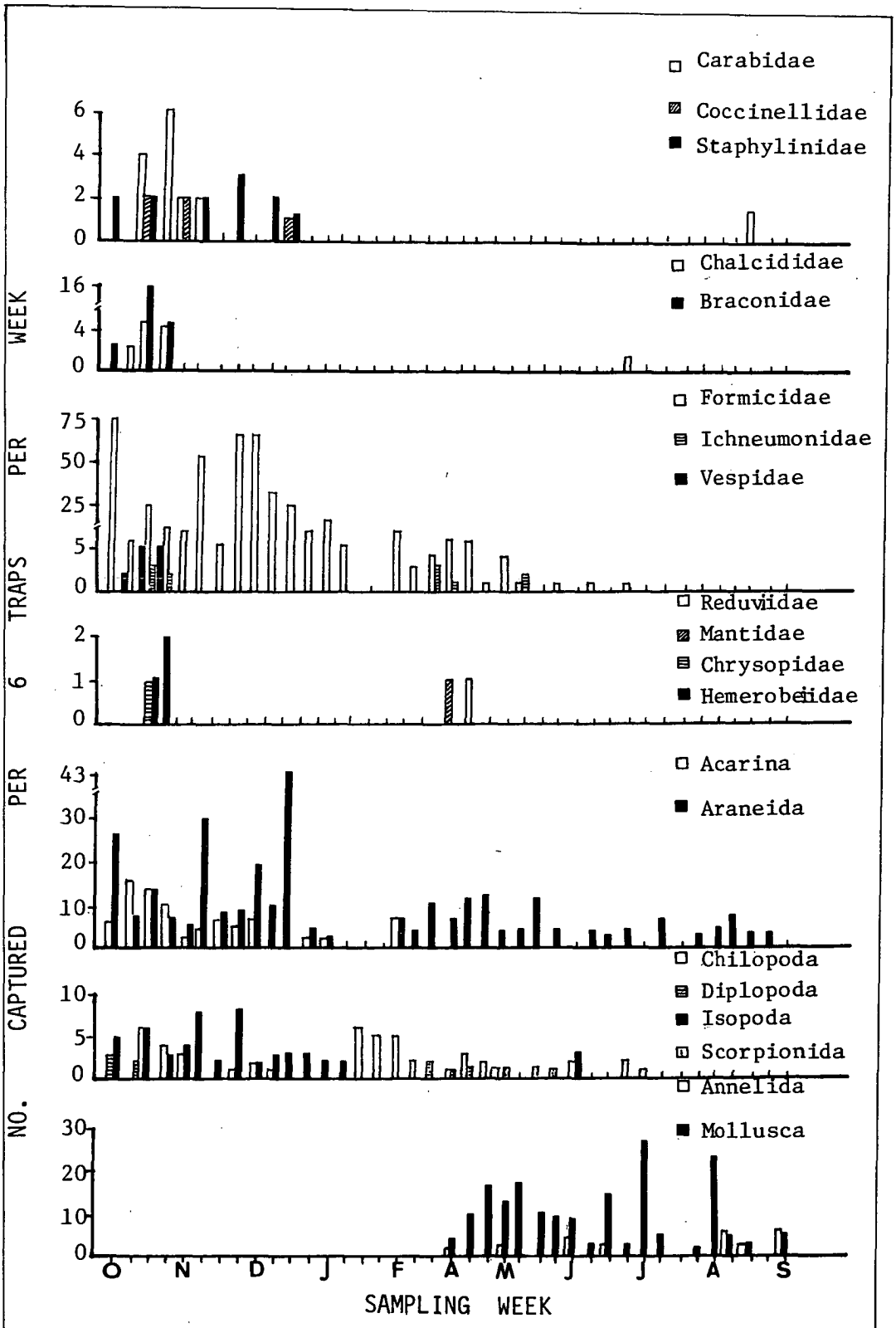



Fig. 4.23. Taxonomic composition of predaceous and parasitic arthropods, molluscs and annelids captured in pitfall traps in unsprayed cabbage plots at S.J.F. College (1982-83).

obtained between the trap catches of ants, spiders, centipedes or isopods and the cabbage aphid population levels on the plants (Table 4.12).

4.3.3.4 Pheromone traps

These traps were used to monitor the activity and/or abundance of adult DM. Mean moth catches on traps, placed within and outside the study area, fluctuated markedly between trapping intervals (Fig. 4.24). Throughout the trapping period more moths were trapped in the interior traps over the crop canopy. However, the catches both within and outside the crops were strongly correlated ($r=0.91$, $P<0.001$, Fig. 4.25).

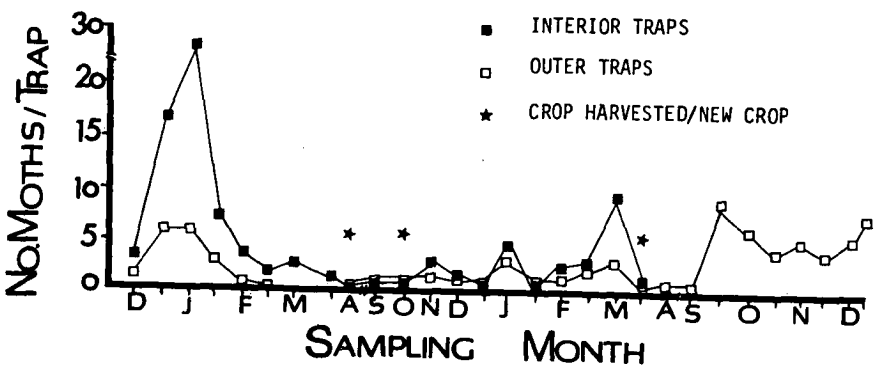



Fig. 4.24. Trends of diamondback moth in interior(within the crop) and outer(outside of crop) pheromone-baited traps at S.J.F.College cabbage crops (1983-85).

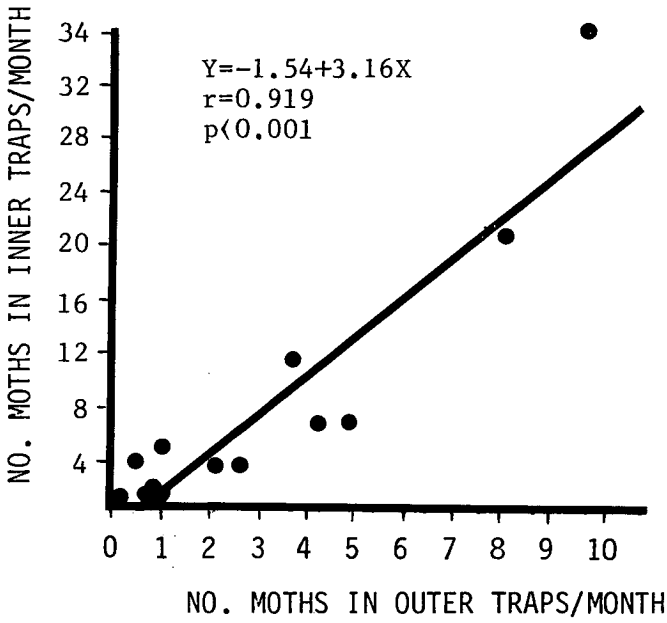



Fig. 4.25. Relationship between diamondback moth captures in outer and inner pheromone traps at S.J.F. College (n=13 month).

Catches of the moth increased in September-December, declined through January-February but increased in March. Larval populations on plants were not correlated to moth catches 7 days previously. However, a strong correlation was obtained between the larval counts and the moth catches obtained 14 days previously (r=0.73 for interior traps and r=0.66 for outer traps, Table 4.13). No strong correlations were obtained when the relationships were analysed on a 21 day basis. The results suggested a lag of almost 14 days between the moth appearance/activity and the larval presence on the cabbage plants.

Occasionally, the larval and pupal parasitoids of this moth were caught in the traps but not in sufficient or consistent numbers to allow any significant interpretation.

### 4.3.3.5 Female attractant

Males of CWB were not attracted to female butterfly

Table 4.12 Relationship between cabbage aphid population levels and concurrent catches of predatory arthropods in pitfall traps (crop I & II, 1982-83).

| X-variable | Y-variable | Regression equation | n | r | p |
|---|---|---|---|---|---|
| Apterae per 9 plants | Ants per 6 traps | Y=55.7-0.17X | 36 | -0.03 | N.S. |
| Apterae per 9 plants | Spiders per 6 traps | Y=69.08-2.10X | 36 | -0.23 | N.S. |
| Apterae per 9 plants | Centipeds per 6 traps | Y=90.2-15.76X | 18 | -0.42 | N.S. |
| Apterae per 9 plants | Isopods per 6 traps | Y=73.6- 4.32X | 9 | -0.34 | N.S. |

N.S. = not significant ( $P > 0.05$ )

Table 4.13 Relationships between P. xylostella mean larvae per cabbage plant and moth catches on previous 7, 14 or 21 days on pheromone-baited traps at S.J.F.College (Dec. 83-Jan. 85).

| | Regression equation and correlation coefficient | |
|---|---|---|
| Offset Days | Interior traps | Exterior traps |
| 7 | Y=0.51+0.17X<br>r=0.47 | Y=0.57+0.33X<br>r=0.40 |
| 14 | Y=0.53+0.105X<br>r=0.73 * | Y=0.48+0.48X<br>r=0.66 |
| 21 | Y=0.54+0.18X<br>r=0.37 | Y=1.03-0.14X<br>r=-0.127 |

* = $P < 0.05$

used as a lure/attractant in field conditions.

The efficiency and/or reliability of each sampling method with respect to the both key and secondary species encountered in this study has been summarized in Table 4.14.

Table 4.14 Efficiency of sampling methods employed to monitor the relative abundance of cabbage pests and associated parasitoids and predators at S.J.F. College cabbage crops (1982-85).

| Species monitored | | Sampling Procedures and its Efficiency | | | | |
|---|---|---|---|---|---|---|
| Common name | Scientific name | Direct counts | Sticky traps | Moericke traps | Pitfall traps | Pheromone traps / Female attractant |
| | | | | # | | |
| **Key species** | | | | | | |
| Cabbage aphid | *B. brassicae* | | | | | |
| Alate | | * | NE | ** | - | - |
| Apterae | | ** | - | - | - | - |
| Cabbage white butterfly | *A. rapae* | | | | | |
| Eggs + Larvae) | | ** | - | - | - | - |
| Adult | | NE | - | - | - | NE |
| Diamondback moth | *P. xylostella* | | | | | |
| Larvae + Pupae) | | ** | - | - | - | - |
| Adult | | NE | NE | NE | - | ** |
| Aphid parasitoid | *D. rapae* | | | | | |
| In mummies | | ** | - | - | - | - |
| Adult wasp | | * | ** | * | - | - |
| Hyperparasitoid | *A. brassicae* | | | | | |
| In mummies | | * | - | - | - | - |
| Adult wasp | | NE | ** | NE | - | - |
| Parasitoids of CWB | *A. glomeratus*<br>*P. puparum* | NE | ** | NE | - | - |
| Parasitoids of DM | *D. rapi*<br>*T. collaris*<br>*A. plutellae* | NE | ** | NE | - | - |
| **Potential predators** | | | | | | |
| Brown lace-wing | *M. tasmaniae* | * | ** | * | - | - |
| Syrphid fly | *M. viridiceps* | * | ** | * | - | - |
| Ladybird beetle | *C. repanda*<br>*L. conformis* | * | * | * | - | - |
| Ants | *Myrmecia* spp. | * | NE | * | ** | - |
| Spiders | *A. pexa*<br>*D. crocata*<br>*C. elaphinus* | NE | - | * | ** | - |

#
* = Efficient
** = Highly efficient
NE = Not efficient
\- = Not compatible to species behaviour

### 4.3.4 Parasitism of insect pests and its relationship to parasitoid abundance monitored by different sampling methods

#### 4.3.4.1 Parasitism of cabbage aphid

Estimates of parasitism obtained from the field counts of mummies and live aphids and collection of live aphids returned and maintained in the laboratory to await parasitoid emergence are given in Fig. 4.19. Parasitism was generally high from the middle to the end of each crop cycle. Although parasitism was persistent throughout the cropping season there was a general decline in the proportion of parasitized aphids during late April to the end of May (crop II). Parasitism (field and total) was high when the aphid populations were very low (1-7 aphids per plant in crop I, II, III). However, in crop V the highest parasitism was obtained when the aphid population rose to >1000 aphids/plant.

Table 4.15 indicates the relationship between the population levels of apterous aphids and parasitism in different crops. Except in crop I parasitism was not significantly associated to the aphid population and there was an indication in crops I and II that lower population of aphids, were more heavily parasitized. The positive and significant ($P<0.05$) correlations were obtained between the sticky trap catches of *D. rapae* and parasitism of aphids on the plants in crop I and III (Table 4.16). In crop II (winter season) the relationship was not stronger between these variables. With the exception of crop V consistently positive correlations were obtained between

Table 4.15 Relationship between cabbage aphid population levels and their parasitism by *D. rapae* (1982-85).

| Crop No. | Season | X-Variable | Y-Variable | Regression equation | n | r | p |
|---|---|---|---|---|---|---|---|
| I | Spring-Summer | Apterous aphids per plant | % Mummies of total aphids | Y=12.96-0.48X | 17 | -0.40 | N.S. |
| II | Autumn-Spring | | | Y=10.45-0.43X | 21 | -0.43 | <0.05 |
| III | Summer-Autumn | | | Y= 7.0+0.17X | 10 | 0.08 | N.S. |
| V | Spring-Autumn | | | Y= 4.53+0.007X | 8 | 0.38 | N.S. |
| I | Spring-Summer | | Total parasitism | Y=12.77+0.54X | 20 | 0.46 | <0.05 |
| II | Autumn-Spring | | | Y=14.1+0.317X | 24 | 0.20 | N.S. |
| III | Summer-Autumn | | | Y=21.18+0.372X | 10 | 0.16 | N.S. |
| V | Spring-Autumn | | | Y=15.9+0.009X | 8 | 0.43 | N.S. |

N.S. = not significant ($P > 0.05$)

Table 4.16 Relationship between the cabbage aphid parasitoid, D. rapae catches on sticky traps (ST) and Moericke traps (MT) and the incidence of total parasitism of cabbage aphid on cabbage plants.

| Crop No. | Season | X-Variable | Y-Variable | Regression equation | n | r | p |
|---|---|---|---|---|---|---|---|
| I | Spring-Summer | Parasitoids per ST | % parasitism | Y=12.9+1.15X | 18 | 0.48 | <0.05 |
| | | Parasitoids per MT | | Y=14.2+2.26X | 18 | 0.38 | N.S. |
| II | Autumn-Spring | Parasitoids per ST | | Y=15.28-0.83X | 23 | 0.06 | N.S. |
| | | Parasitoids per MT | | Y=1.42+32.2X | 5 | 0.67 | N.S. |
| III | Summer-Autumn | Parasitoids per ST | | Y=12.7+33.9X | 10 | 0.69 | <0.05 |
| | | Parasitoids per MT | | Y=15.6+10.16X | 8 | 0.50 | N.S. |
| V | Spring-Autumn | Parasitoids per ST | | Y=12.97+1.53X | 10 | 0.34 | N.S. |
| | | Parasitoids per MT | | Y=29.14-6.19X | 4 | -0.76 | N.S. |

N.S. not significant ($P > 0.05$)

the Moericke trap catches of the parasitoids and the % parasitism of aphids on cabbage plants.

4.3.4.2 Parasitism of cabbage white butterfly

The braconid parasitoid, A. glomeratus, was reared from parasitized CWB larvae. The first larval generation of CWB and the first collection of parasitized larvae were asynchronous. However, the parasitism increased with the decrease in larval population and a significant correlation ($P<0.05$) was obtained between parasitism and larval populations (Fig. 4.26).

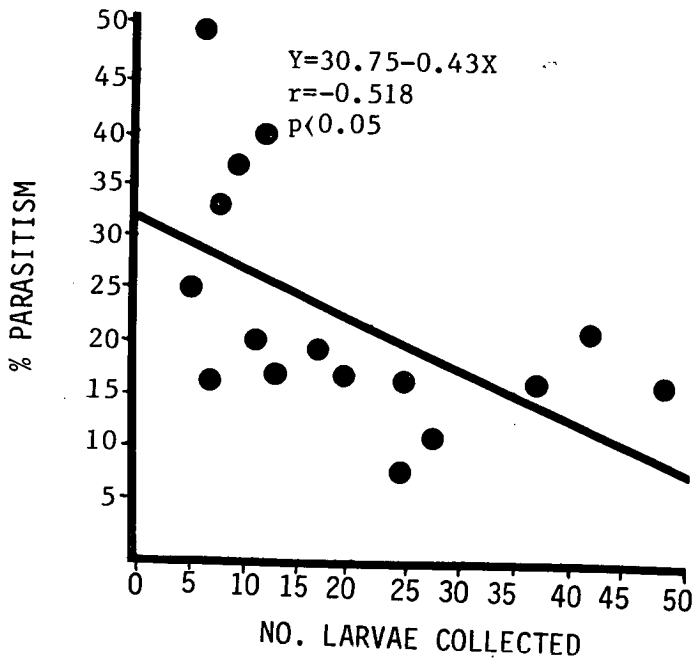



Fig. 4.26. Relationship between cabbage white butterfly larval population and its parasitism by the parasitoid, A. glomeratus.

Parasitism was usually high during the 2nd half of the croping season indicating the relatively enhanced susceptibility of CWB larvae to parasitism at later growth stages of cabbage plant. Parasitism on a monthly basis varied from 8-50% and averaged 22.4, 26.6, 22.4 and 22.2% in crops I, II, III and V respectively (Table 4.17).

Pupal parasitism by the parasitoid, P. puparum was very low in each crop, ranging from 0-33%, however, trends in the parasitism were consistent with pupal densities in the field.

### 4.3.4.3 Parasitism of diamondback moth

The following species of parasitoids were reared from the larvae or pupae of DM :

1. Diadegma rapi (Ichneumonidae : Ophioninae)
2. D. eucerophaga (Ichneumonidae : Ophioninae)
3. Thyraeella collaris (Ichneumonidae : Ichneumoninae)
4. Apanteles plutellae (Braconidae : Microgastrinae)
5. Diplazon laetatorius (Ichneumonidae : Mesochorinae)

In the crops examined D. rapi and D. eucerophaga in combination resulted in high parasitism (48%) during January-February (Fig. 4.21). In crop I, these parasitoids were not well synchronized with the first larval generation, however, the later trends showed that parasitism by D. rapi increased with increase in the larval host population. Maximum parasitism due to D. rapi

Table 4.17 Parasitism of *A. rapae* by the larval parasitoid, *A. glomeratus* and pupal parasitoid, *P. puparum*.

| Crop | Subject | Monthly levels | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | S | O | N | D | J | F | |
| I | No.Larvae collected | - | 24 | 41 | 48 | 10 | 4 | |
| | % Parasitism | - | 8.3 | 21.9 | 16.6 | 40 | 25 | |
| | No. Pupae collected | - | - | 5 | 6 | 3 | - | |
| | % Parasitism | - | - | 0 | 16.6 | 0 | - | |
| | | M | A | M | J | J | A | S |
| II | No. Larvae collected | - | 10 | 6 | - | - | - | - |
| | % Parasitism | - | 20 | 33.3 | - | - | - | - |
| | No. Pupae collected | - | - | - | - | - | - | - |
| | % Parasitism | - | - | - | - | - | - | - |
| | | N | D | J | F | M | | |
| III | No. Larvae collected | - | 12 | 36 | 16 | 8 | | |
| | % Parasitism | - | 16.6 | 16.6 | 18.7 | 37.5 | | |
| | No. Pupae collected | - | 1 | 1 | 3 | 3 | | |
| | % Parasitism | - | - | 0 | 0 | 0 | | |
| | | O | N | D | J | F | M | |
| V | No. Larvae collected | - | 6 | 24 | 27 | 18 | 4 | |
| | % Parasitism | - | 16.6 | 16.6 | 11.1 | 16.6 | 50 | |
| | No. Pupae collected | - | - | 3 | 6 | - | - | |
| | % Parasitism | - | - | 0 | 33.3 | - | - | |

was 40% in December (crop I) and late February (crop V). However, D. eucerophaga parasitism occured only in crop I and in other crops no parasitism by this species was detected despite the fact that this parasitoid was caught on sticky traps in crop III.

Parasitism due to A. plutellae was very low, peaking in late November in crop I. Parasitism by T. collaris was slightly higher than that of A. plutellae and it was more persistent in crop III (5-20%). Hyperparasitism of the parasitoids (D. rapi and D. eucerophaga) was very low and only on two occasions a hyperparasitoid, Diplazon laetatorius was reared from the parasitized prepupae of DM.

The data presented in Table 4.18 suggest that despite the reasonable population levels of D. rapi monitored by sticky traps, parasitoid numbers were not strongly correlated with its host population in any crop yet it achieved marked percentages of parasitism. Although there was no significant correlation between the percentage parasitism, monitored by rearing the field collected larval samples, and the larval host population on plants in crops I and II, the two variables were strongly correlated ($P<0.01$) in crop III (Table 4.19). Conversely, a significant but negative correlation in the crop V suggested an increased activity of the parasitoid with host population decline.

Sticky trap catches reflected the field activity of the parasitoid and mild to very strong ($P<0.05-0.01$) positive correlations were obtained (Table 4.20). Winter

Table 4.18 Correlation-regression of the abundances of DM and its parasitoid, D. rapi at S.J.F. College (1982-85).

| Crop No. | Season | X-Variable (Host per plant) | Y-Variable (parasitoid) | Regression equation | n | r | p |
|---|---|---|---|---|---|---|---|
| I | Spring-Summer | Larvae | Adult wasps per sticky traps | Y=1.04+1.14X | 11 | 0.27 | N.S. |
| | | Larvae+Pupae | | Y=0.83+1.056X | 11 | 0.36 | N.S. |
| II | Autumn-Spring | Larvae | | Y=0.90+1.09X | 9 | 0.38 | N.S. |
| | | Larvae+Pupae | | Y=0.77+1.14X | 9 | 0.43 | N.S. |
| III | Summer-Autumn | Larvae | | Y=1.14+0.56X | 10 | 0.48 | N.S. |
| | | Larvae+Pupae | | Y=1.07+0.50X | 10 | 0.56 | N.S. |
| V | Spring-Autumn | Larvae | | Y=2.13+0.04X | 7 | 0.008 | N.S. |
| | | Larvae+Pupae | | Y=2.14+0.02X | 7 | -0.007 | N.S. |

N.S. = not significant (P>0.05).

Table 4.19 Correlation-regression of the abundance of DM and its parasitism by D. rapi at S.J.F. College (1982-85).

| Crop No. | Season | X-Variable (Host per plant) | Y-Variable | Regression equation | n | r | p |
|---|---|---|---|---|---|---|---|
| I | Spring-Summer | Larvae | % parasitism | Y=20.25+9.8X | 13 | 0.26 | N.S. |
| | | Larvae+Pupae | | Y=18.34+8.93X | 13 | 0.31 | N.S. |
| II | Autumn-Spring | Larvae | | Y=20.8+1.35X | 8 | 0.03 | N.S. |
| | | Larvae+Pupae | | Y=13.25+14.5X | 9 | 0.41 | N.S. |
| III | Summer-Autumn | Larvae | | Y=8.68+8.61X | 10 | 0.74 | * |
| | | Larvae+Pupae | | Y=8.09+6.95X | 10 | 0.78 | ** |
| V | Spring-Autumn | Larvae | | Y=31.6-30.0X | 7 | -0.67 | * |
| | | Larvae+Pupae | | Y=31.38-18.3X | 7 | -0.65 | * |

N.S. : Not Significant (P>0.05), *=P<0.05, ** = P<0.01

Table 4.20 Correlation - regression of the abundance of the parasitoid, D. rapi, on sticky traps and percent parasitism of DM larvae on cabbage plants at S.J.F. College (1982-85).

| Crop No. | Season | X-Variable | Y-Variable | Regression equation | n | r | p |
|---|---|---|---|---|---|---|---|
| I | Spring-Summer | Parasitoids caught per sticky trap | % parasitism of larvae | Y=4.52+14.55X | 11 | 0.75 | ** |
| II | Autumn-Spring | | | Y=14.16+5.66X | 8 | 0.51 | N.S. |
| III | Summer-Autumn | | | Y=1.64+8.29X | 10 | 0.83 | ** |
| V | Spring-Autumn | | | Y=5.19+8.94X | 9 | 0.71 | * |

N.S.=not significant (P>0.05) , *=P<0.05 , **=P<0.01

conditions in crop II suppressed the parasitoid's activity, however, in summer crops, consistent and compatible relationships were obtained between the sticky trap catches and the percentage parasitism in the field.

### 4.3.5 Seasonal pest populations in relation to physiological time

#### 4.3.5.1 Cabbage aphid

The calculated heat units ( HU's) or degree-days (DD) and the peaks of successive generations obtained by visual assessment of fluctuating aphid populations are presented in Fig. 4.27. The data show the highly variable nature of population development of this species. Overlapping generations were a common feature which made the analysis difficult. However, using the reported developmental threshold of 5°C (Hughes, 1963) HU's were calculated between the period of each population peak. There were 233±14.6 and 223±13.5 HU's calculated for each generation in crops I and II respectively (Table 4.21).

Table 4.21 Comparison between estimated and observed heat units (HU's) accumulation at the beginning of each generation of cabbage aphid in cabbage crops I and II at S.J.F. College (1982). +

| Generation No. | Estimated HU's (Hughes, 1963) | Actual accumulated HU's Crop I | Crop II |
|---|---|---|---|
| 1 | 250 | 250 | 230 |
| 2 | 500 | 483 | 455 |
| 3 | 750 | 695 | 688 |
| 4 | 1000 | 920 | 891 |
| 5 | 1250 | 1169 | - |
| 6 | 1500 | 1398 | - |
| Mean±S.E | 250±? | 233±14.6 | 223±13.5 |

+ Developmental threshold=5 °C (Hughes, 1963).

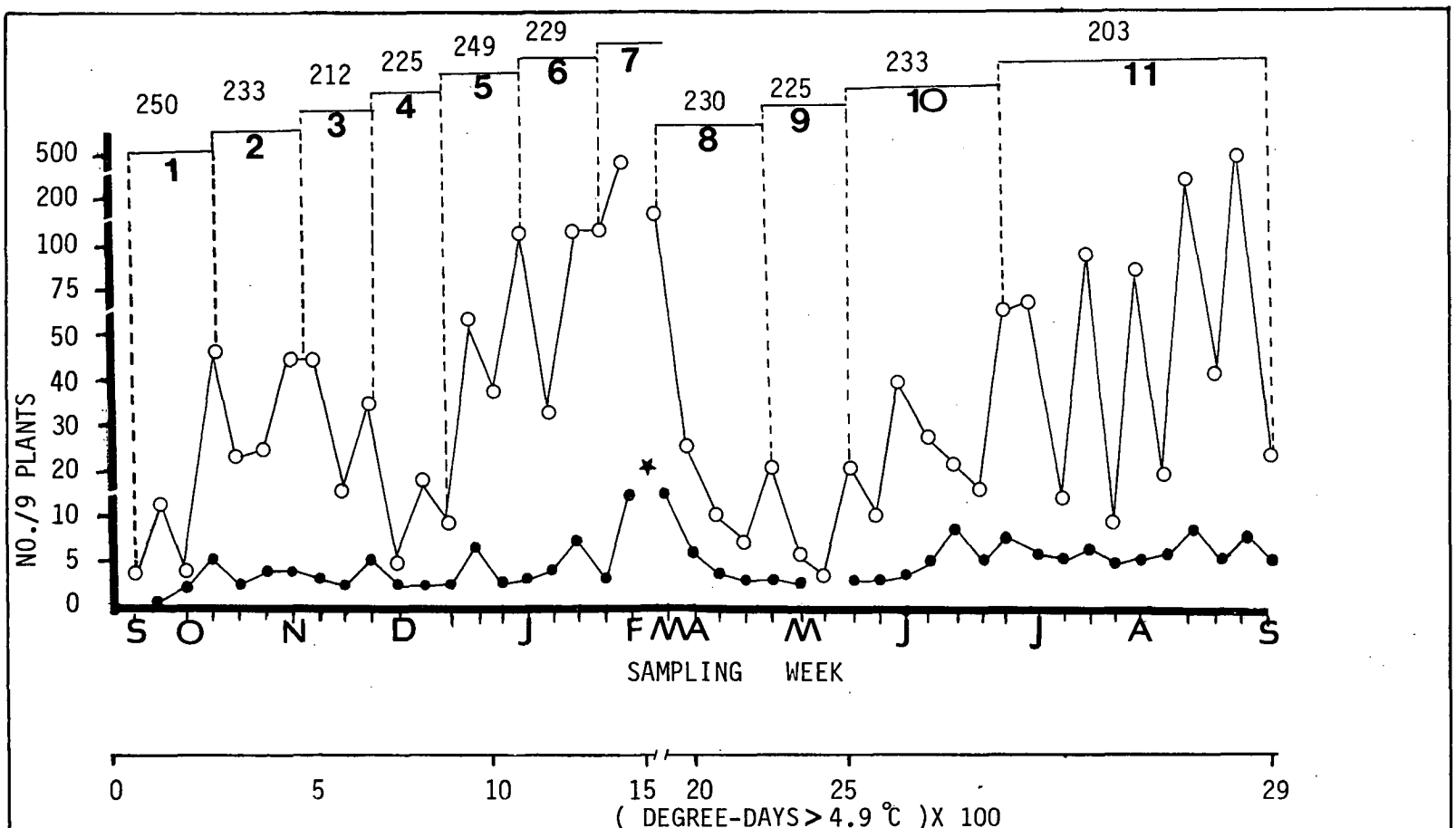



Fig. 4.27. Population cycles of live cabbage aphids(o—o) and parasitised aphid mummies(●—●) in relation to heat units.Number in dotted bar denotes generation number while the number above the bar represents heat units calculated for each generation.

* Time lag between the two crops amounted 599 degree-days/heat units above 4.9℃ taken as developmental threshold for cabbage aphid.

Actual HU's accumulated between observed peaks varied from 203 to 250. This variation could have resulted from either accumulation of excessive number of HU's between overlapping generations or an inability to identify the real population peaks. However, altogether 10 complete and 1 incomplete generations were identified. Considering the time lapse between the 2 crops when 599 HU's were calculated, at least 2 complete generations could be expected in this interval. Thus a total of 13 generations may be projected on the basis of the accumulated HU's.

4.3.5.2 Cabbage white butterfly

The calculated HU's in relation to the population peaks of successive generations of CWB are shown in Fig. 4.28. On the basis of actual accumulated HU's required for one generation (231±20) 4 complete generations were observed. At least 1 generation may have been missed because of the time lapse between crop I and crop II. Thus a total of 5 generations may be projected throughout the year at S.J.F. College. Calculation showed that the average 231±20 HU's agreed fairly well with the expected HU's for a generation (Table 4.22).

Table 4.22 Comparison between estimated and observed heat units (HU's) accumulation at the beginning of each generation of cabbage white butterfly at S.J.F.College (1982-83).+

| Generation No. | Estimated HU's (Davies and Gilbert, 1985) | Actual accumulated HU's Crop I | Crop II |
|---|---|---|---|
| 1 | 211 | 228 | 218 |
| 2 | 422 | 489 | - |
| 3 | 633 | 708 | - |
| Mean±S.E | 211±? | 231±20 | |

+ Developmental threshold=10 °C (Davies and Gilbert,1985).

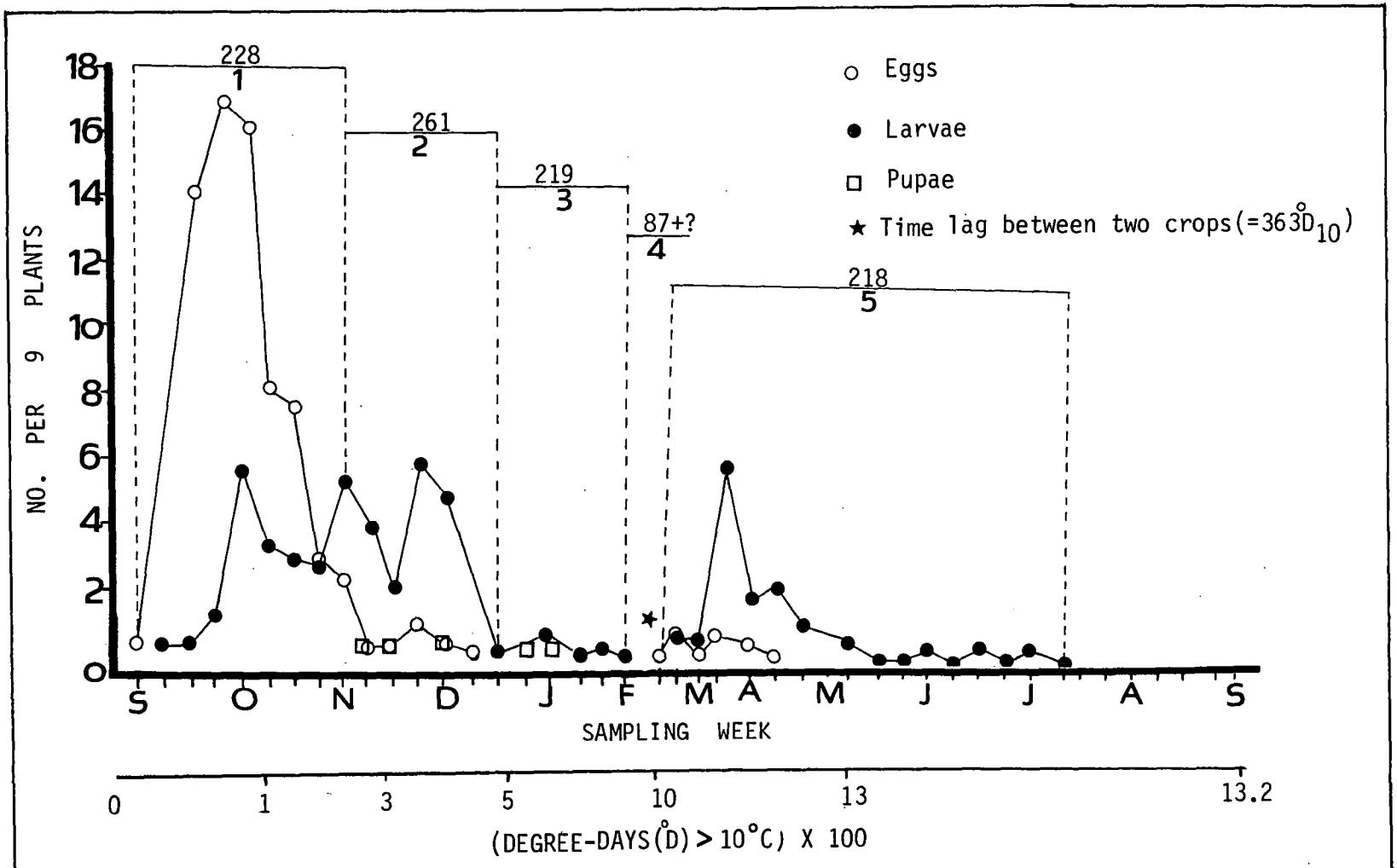



Fig. 4.28. Population cycles of cabbage white butterfly in relation to heat units. Number in dotted bar denotes generation number while the number above the bar represents °D calculated for each generation.

#### 4.3.5.3 Diamondback moth

Figure 4.29 shows the calculated HU´s in relation to the population peaks of the successive generations of DM. On the basis of actual accumulated HU´s above a threshold of 7.3°C, at least 4 complete generations were determined with an average generation time of 306±9.5 HU´s (Table 4.23). Egg counts were not made in this study, otherwise a correlation between the eggs appearance and larval peaks might have been established. Taking into consideration the time lapse between crops I and II and with each generation requiring an average 306±9.5 HU´s, overall 5 DM generations may be projected at the experimental site.

Table 4.23 Comparison between estimated and observed heat units (HU´s) accumulation at the begining of each generation of diamondback moth in cabbage crops I and II at S.J.F. College (1982-83). +

| Generation No. | Estimated HU´s (Butts and McEwen, 1981 | Actual accumulated HU´s Crop I | Crop II |
|---|---|---|---|
| 1 | 293 | 292 | 311 |
| 2 | 586 | 600 | - |
| 3 | 879 | 913 | - |
| Mean±S.E | 293±16.7 | 306±9.5 | |

+ Developmental threshold=7.3°C (Butts and McEwen, 1981).

### 4.3.6 Seasonal within-plant distribution of insect pests

#### 4.3.6.1 Aphids

Three aphid species namely green peach aphid, M. persicae, cabbage aphid, B. brassicae and potato aphid, Macrosiphum euphorbiae, were found on the cabbage plants during September-November in crop I.

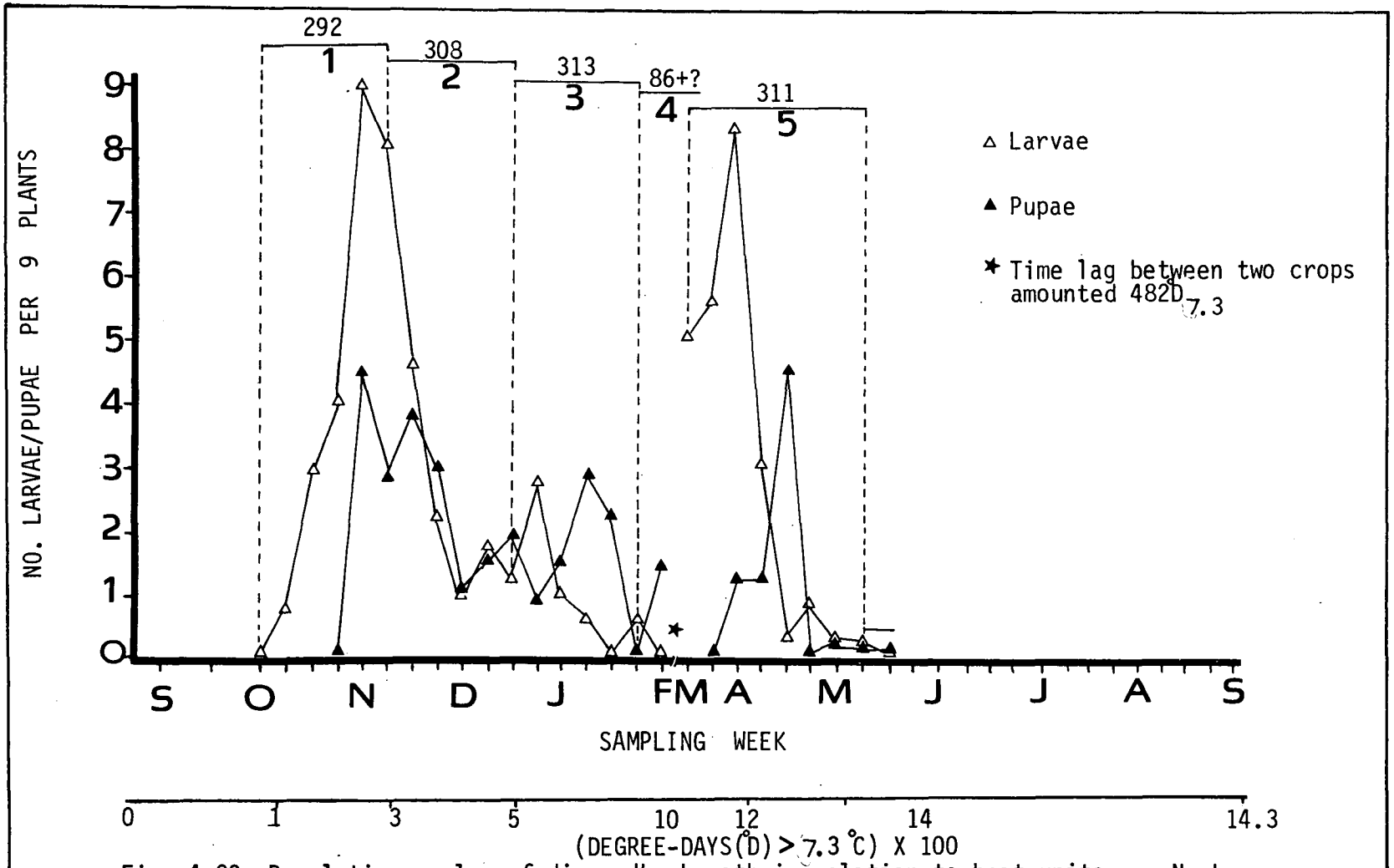



Fig. 4.29. Population cycles of diamondback moth in relation to heat units. Number in dotted bar denotes generation number while the number above the bar represents D calculated for each generation.

The green peach aphid was the dominant species in the early growth stages of the cabbage plant and accounted for 50-90% of the total aphid population. However, during early summer cabbage aphid became more abundant (Fig. 4.30). The potato aphid was recorded in low numbers from October - early November. The green peach aphid and potato aphid were not abundant later in the season, however, their patterns of distribution during early growth stage of cabbage plants were strikingly different from that of cabbage aphid. Cabbage aphid was recorded on the middle (mature) or upper (youngest) leaves where as green peach aphid and potato aphid generally occured on the lower (oldest) senescing leaves (Figs. 4.30-4.32). Cabbage aphid colonies were initially found on the undersurface of cabbage leaves but during heavy infestations aphids were found on both the upper and under surfaces.

#### 4.3.6.2 Cabbage white butterfly

The cabbage white butterfly exhibited a significant preference (77%) to oviposit on the middle leaves of the cabbage plants throughout the growing season. Smaller proportion of eggs were recorded on the lower (9.3%) and upper leaves (13.7%) (Fig. 4.33).

Upto cupping stage, 85-100% of CWB larvae were recorded on the middle leaves but this proportion decreased as the plants approached head formation when greater proportions (73-100%) of larvae were found on the upper leaves (Fig. 4.34).

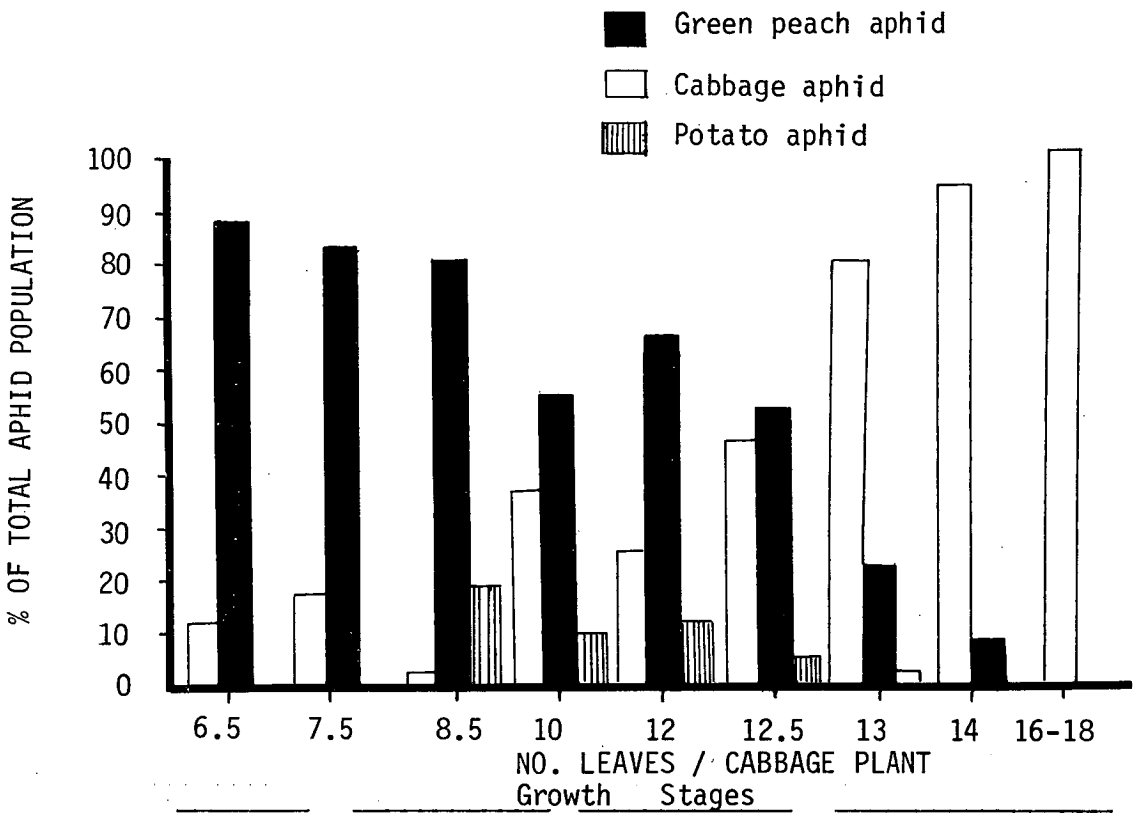



Fig.4.30. Relative occurrence of aphid species on cabbage plants.

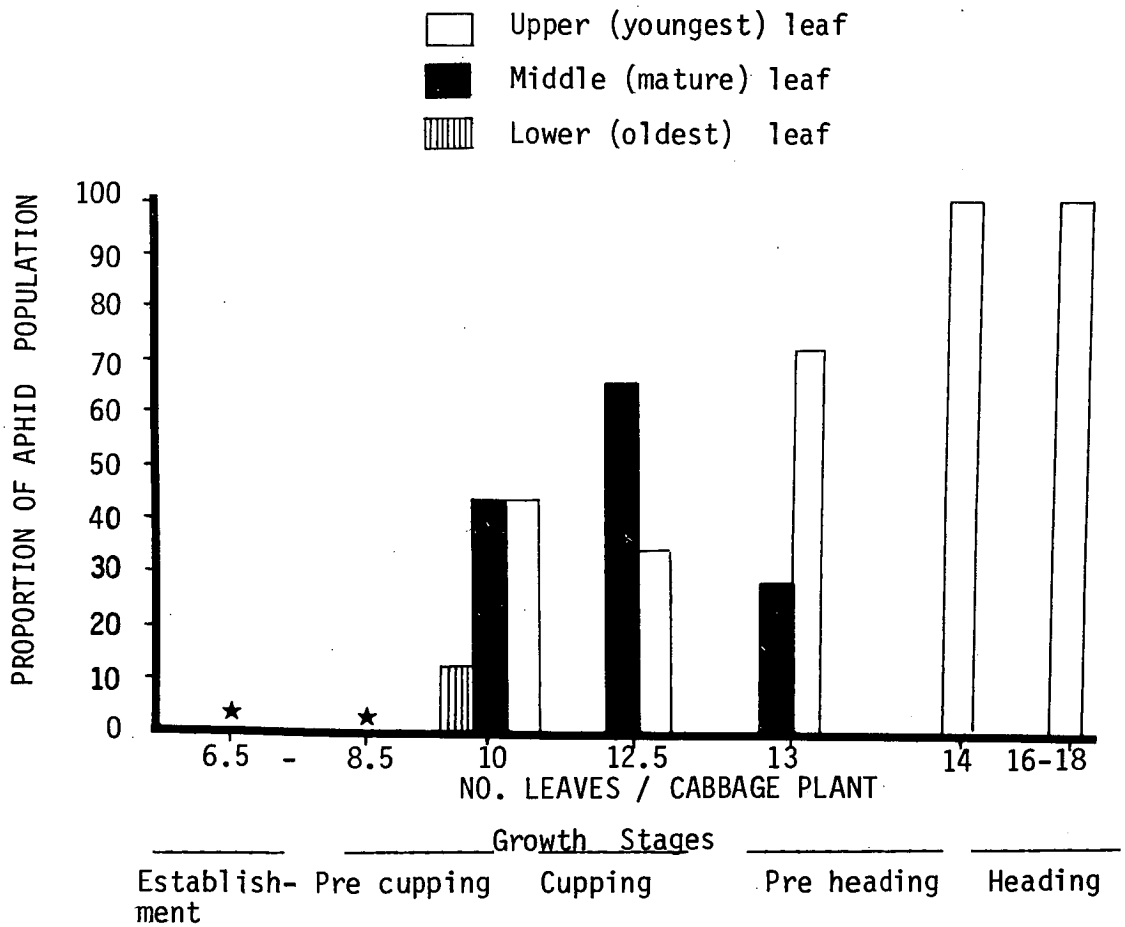



Fig.4.31. Distribution of cabbage aphid on cabbage plant leaves. Star indicates the sampling stage when less than 25 aphids/9 plants were recorded.

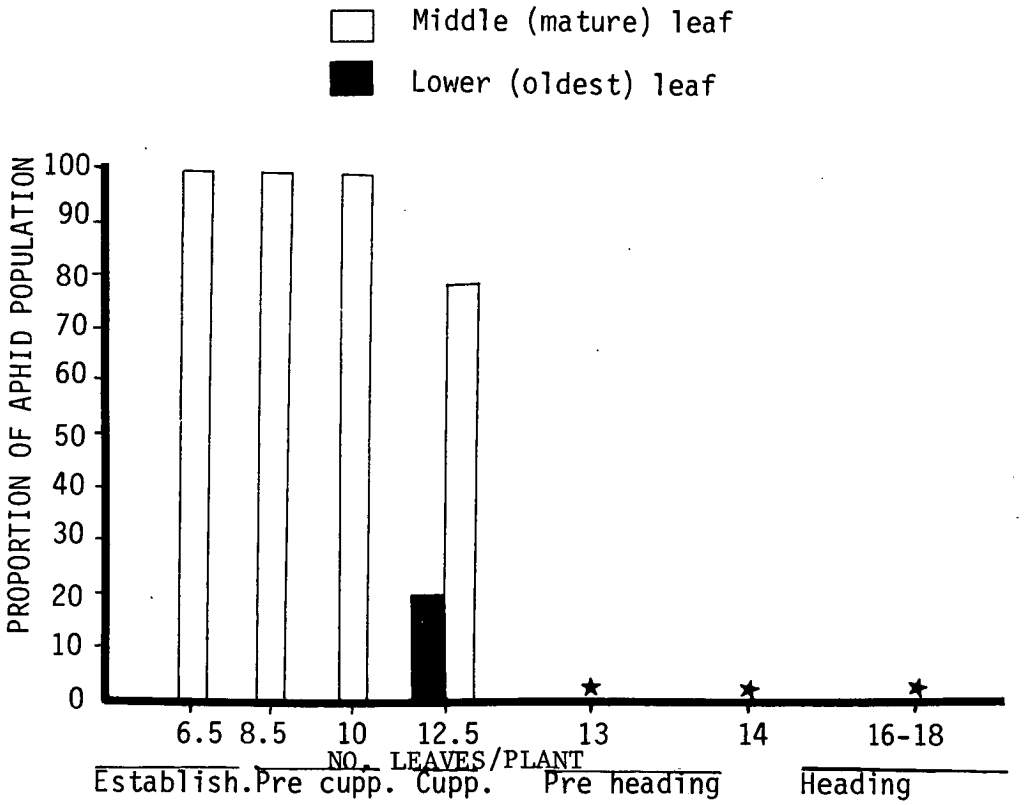



Fig. 4.32. Population distribution of green peach aphid on cabbage plant leaves. Star indicates the sampling stage when less than 25 aphids/9 plants were recorded.

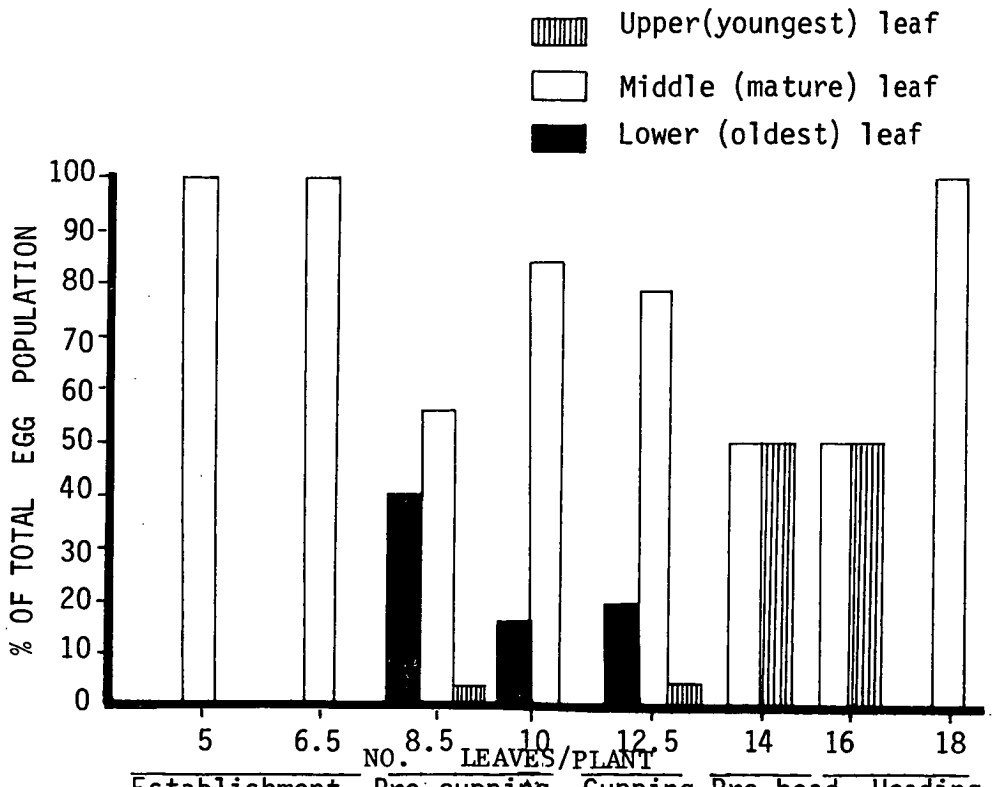



Fig. 4.33. Distribution of CWB egg population on cabbage plants at S.J.F.College plots (1982-83).

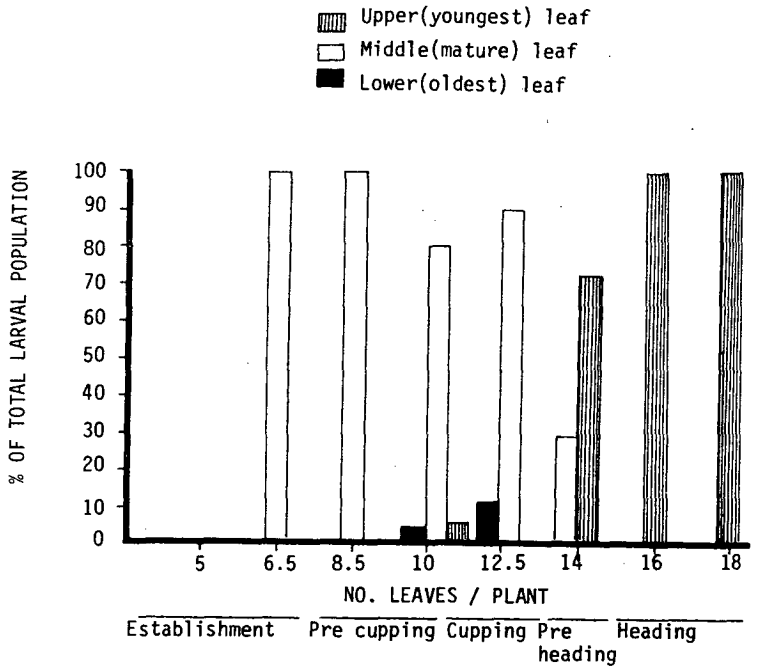



Fig. 4.34. Distribution of CWB larval population on cabbage plants at S.J.F.College plots (1982-83).

4.3.6.3 Diamondback moth

In contrast to the CWB, this moth preferred to oviposit on the upper leaves. Only a small proportion (12.8%) of the total eggs were recorded on middle leaves (Fig. 4.35). The egg counting was later abandoned because of the difficulty in finding the egg masses especially on curly wrapper leaves.

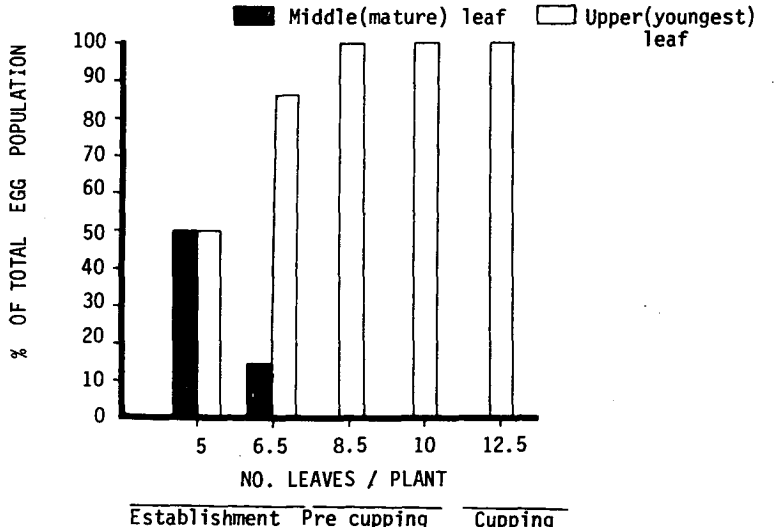



Fig. 4.35. Distribution of DBM egg population on cabbage plants.

During post seedling stage DM larvae were found on the middle leaves but soon after major proportions (60-100%) of the total larval population were recorded/fed on the upper leaves particularly during head formation stage larvae were always found on the upper leaves (Fig. 4.36). Likewise, the major proportion of pupal populations (85%) was recorded on the upper leaves (Fig. 4.37). Thus the most preferred site for oviposition, feeding and population of this species was the upper (youngest) leaves of cabbage plant.

### 4.3.7 Spatial distribution/dispersion of cabbage pests in field crops

Spatial distributions of cabbage insect pests were determined using various dispersion indices. Attempts were made to assess and interpret the precision of different indices relative to the pest population densities and their changes in time.

#### 4.3.7.1 Cabbage aphid

##### 4.3.7.1.1 Alate

Alate CA populations were aggregated during early and late seasons in crop I (summer crop) and throughout most of the season in crop II (winter crop) (Table 4.24). Populations were only randomly distributed on 5 of 32 sampling dates. There was no consistency in the variance/mean $S^2/\bar{X}$ ratio throughout the seasons yet it remained more than 1.0 on 24 of 32 sampling occasions. A significant relationship ($r=0.552$, $P<0.01$) was obtained

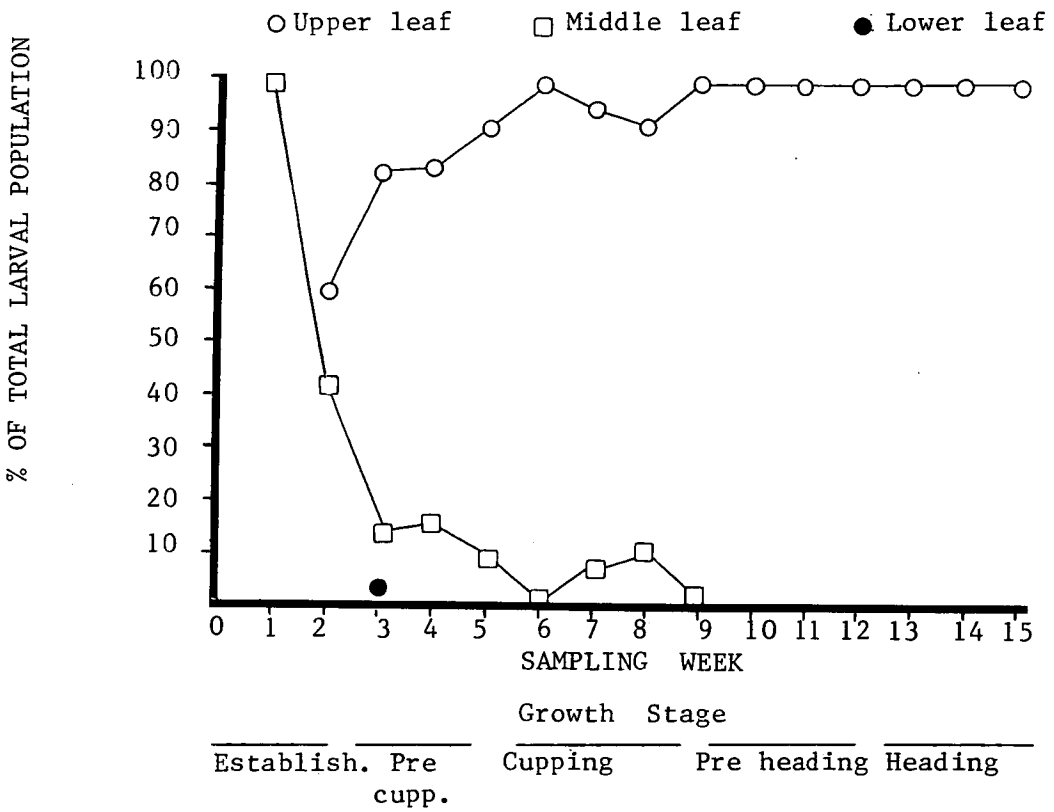



Fig. 4.36. Distribution of DBM larval population on cabbage plants at S.J.F. College plots (1982-83)

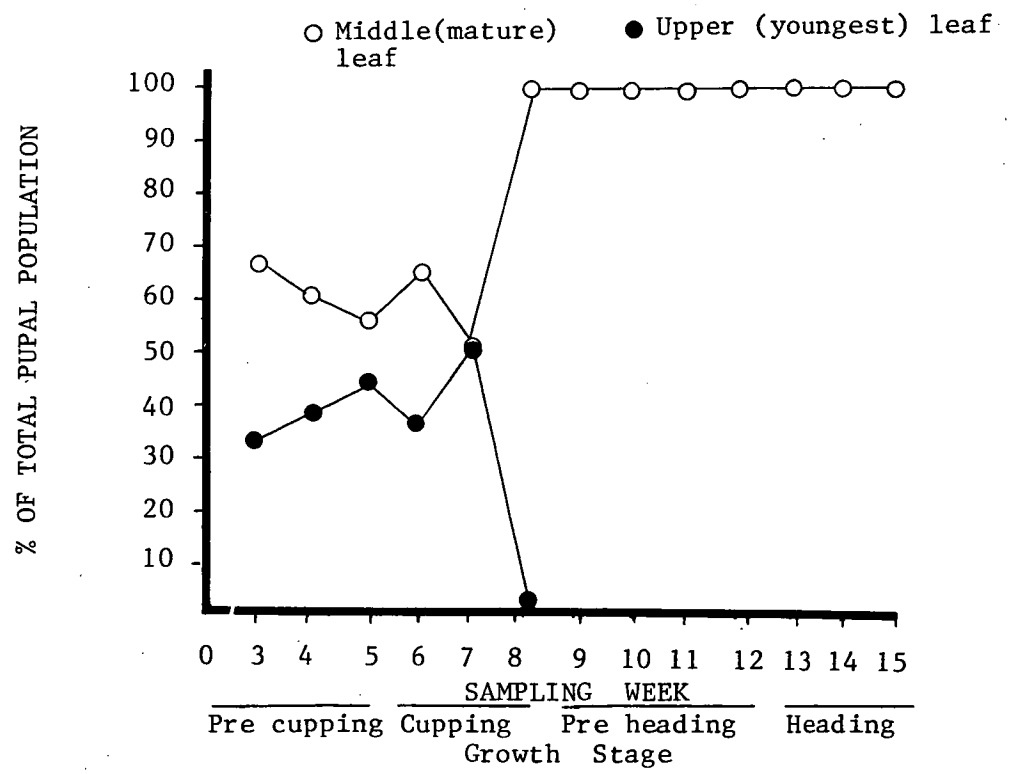



Fig. 4.37. Distribution of DBM pupae on cabbage plants at S.J.F. College plots (1982-83).

Table 4.24 Indices of dispersion for populations of *B. brassicae* alate (1982-83).

| Date of sampling | Mean ($\bar{X}$) | Variance/ Mean ($S^2/\bar{X}$) | Mean crowding ($\overset{*}{X}$) | Lloyd's patchiness index ($\overset{*}{X}/\bar{X}$) | Green's coefficient of dispersion (Cx) |
|---|---|---|---|---|---|
| | | Crop I (Spring-Summer) | | | |
| 15 Sep. | 0.055 | 4.18 | 3.24 | 58.83 | 1.59 |
| 22 Sep. | 0.129 | 2.56 | 1.69 | 13.00 | 0.26 |
| 29 Sep. | 0.814 | 2.56 | 2.37 | 2.91 | 0.06 |
| 6 Oct. | 0.111 | 2.79 | 1.90 | 17.14 | 0.36 |
| 13 Oct. | 0.333 | 1.41 | 0.74 | 2.23 | 0.03 |
| 20 Oct. | 0.296 | 1.93 | 1.22 | 4.13 | 0.07 |
| 27 Oct. | 0.220 | 2.09 | 1.31 | 5.95 | 0.10 |
| 3 Nov. | 0.460 | 1.30 | 0.76 | 1.65 | 0.01 |
| 10 Nov. | 0.440 | 1.43 | 0.87 | 1.98 | 0.02 |
| 17 Nov. | 0.462 | 1.36 | 0.79 | 1.86 | 0.02 |
| 24 Nov. | 0.425 | 0.94 | 0.37 | 0.86 | -0.03 |
| 1 Dec. | 0.018 | 1.00 | 0.02 | 1.00 | 0.00 |
| 8 Dec. | 0.148 | 1.12 | 0.27 | 1.81 | 0.02 |
| 15 Dec. | 0.018 | 1.00 | 0.02 | 1.00 | 0.00 |
| 22 Dec. | 0.314 | 2.38 | 1.70 | 5.40 | 0.09 |
| 29 Dec. | 0.129 | 2.94 | 2.07 | 16.03 | 0.48 |
| 5 Jan. | 0.314 | 3.70 | 3.02 | 9.60 | 0.17 |
| 12 Jan. | 0.259 | 3.23 | 2.49 | 9.61 | 0.09 |
| 19 Jan. | 0.518 | 9.31 | 8.82 | 17.03 | 0.31 |
| 26 Jan. | 0.870 | 21.30 | 21.17 | 24.33 | 0.44 |
| 2 Feb. | 0.185 | 2.25 | 1.44 | 7.77 | 0.10 |

Table 4.24 (continued)

| Date of sampling | Mean ($\bar{X}$) | Variance/ Mean ($S^2/\bar{X}$) | Mean crowding ($\overset{*}{X}$) | Lloyd's patchiness index ($\overset{*}{X}/\bar{X}$) | Green's coefficient of dispersion (Cx) |
|---|---|---|---|---|---|
| | | Crop II (Autumn-Spring) | | | |
| 5 Mar. | 1.833 | 2.38 | 3.22 | 1.75 | 0.01 |
| 3 Apr. | 0.018 | 1.00 | 0.02 | 1.00 | 0.00 |
| 13 Apr. | 0.018 | 1.00 | 0.02 | 1.00 | 0.00 |
| 18 Apr. | 0.018 | 1.00 | 0.02 | 1.00 | 0.00 |
| 18 May. | 0.036 | 2.01 | 1.05 | 29.05 | 1.01 |
| 2 Jun. | 0.036 | 2.01 | 1.05 | 29.05 | 1.01 |
| 8 Jun. | 0.018 | 1.00 | 0.02 | 1.00 | 0.00 |
| 6 Jul. | 0.111 | 6.00 | 5.11 | 46.00 | 1.00 |
| 13 Jul. | 0.018 | 1.00 | 0.02 | 1.00 | 0.00 |
| 18 Aug. | 0.277 | 3.59 | 2.87 | 10.35 | 0.15 |
| 1 Sep. | 0.036 | 2.01 | 1.05 | 29.05 | 1.01 |

when $S^2/\bar{X}$ was regressed on $\bar{X}$ in the summer crop but not significant (r=0.153) for winter crop (Fig. 4.38 A).

In Lloyd's patchiness indices ($\overset{*}{X}/\bar{X}$), values greater than 1.0 represent aggregated distributions with no upper limit. Figure 4.38 B shows the trends in patchiness with mean population density in time. Populations were aggregated ($\overset{*}{X}/\bar{X}>1$) and the dispersion did not show any consistent response to density changes.

The values of Green's coefficient of dispersion (Cx) clearly showed the development of extreme clumping in time. Green's coefficient tended to decrease with increase in the aphid densities in summer crop however, in winter crop mixed trends of random (Cx=0.0) and aggregated (Cx approaching 1.0) dispersions were experienced. Taylor's power law fitted the population data for both crops better than Iwao's regression (Fig. 4.39). Values of b derived by the power law were lower than Iwao's $\beta$. Mean crowding ($\overset{*}{X}$) did not exactly increase in proportion to the increase in mean population density ($\bar{X}$).

4.3.7.1.2 Apterae

Apterous aphid populations were highly aggregated especially during the last half season for crop I and II (Tables 4.25, 4.26). The variance/mean ($S^2/\bar{X}$) and mean crowding ($\overset{*}{X}$) indices trended to increase with increase in density of apterae. The trends in dispersion characteristics of apterous aphids were more consistent than those of alatae. All indices showed similar trends of dispersion and their respective values were more than 1.0

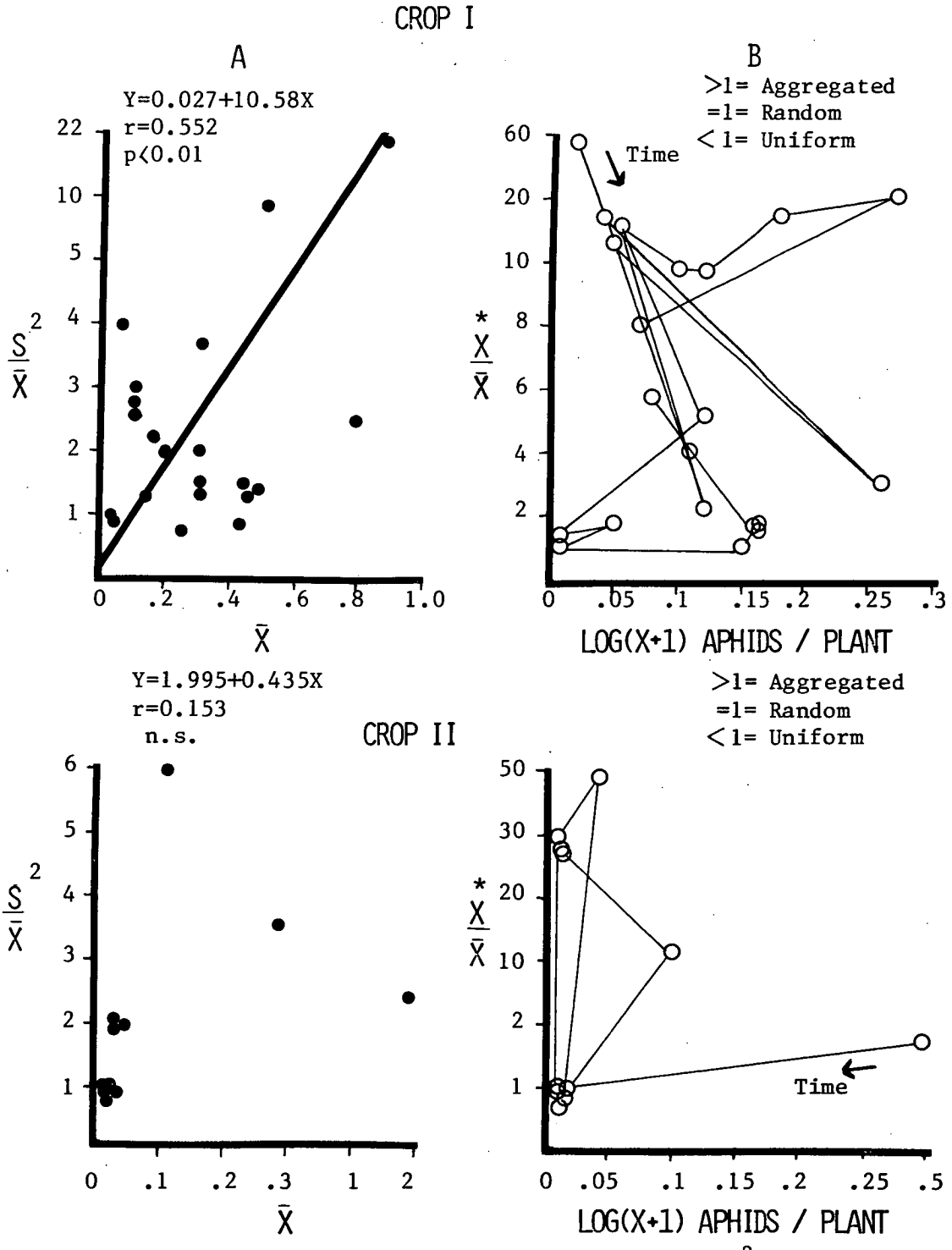
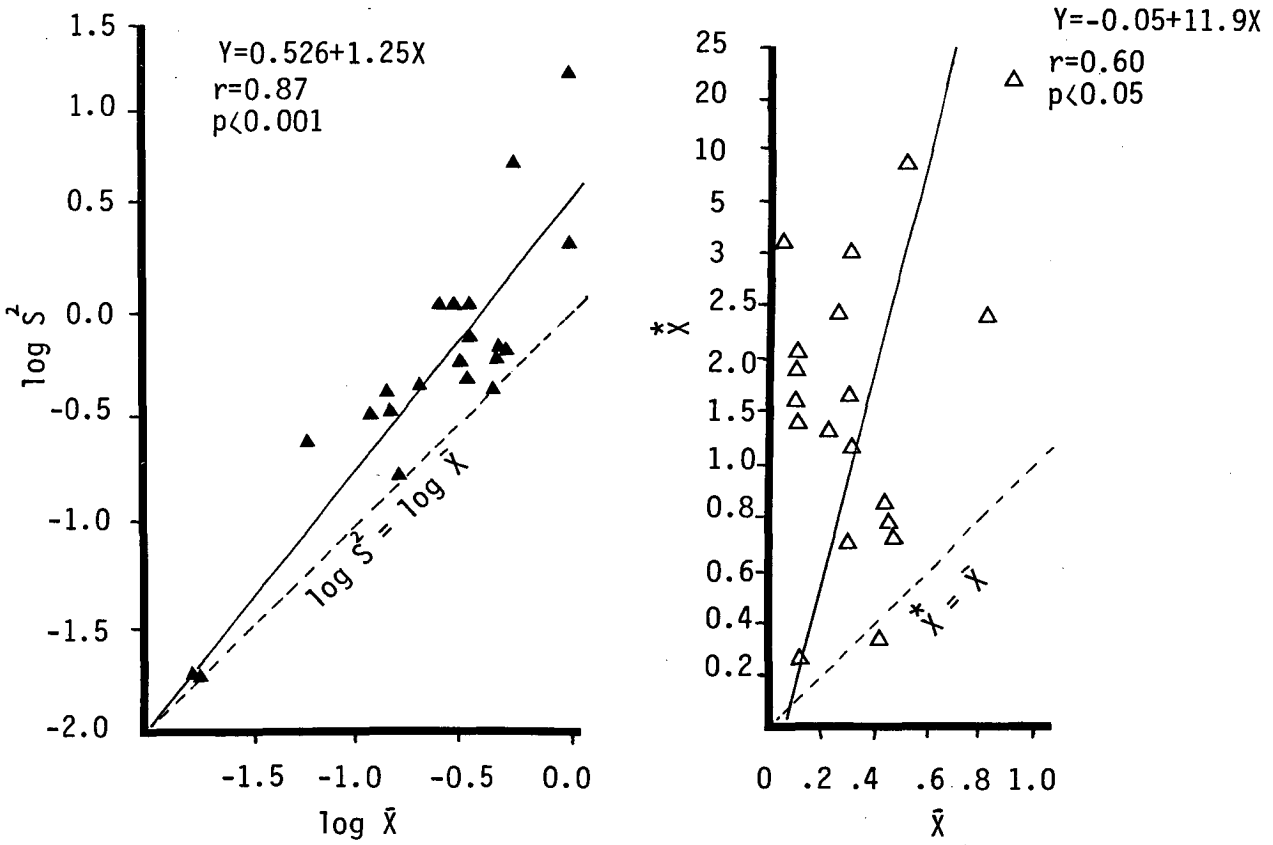



Fig. 4.38. A. Relationship of Variance/Mean ratio($S^2/\bar{X}$) to Mean density ($\bar{X}$) of alate cabbage aphids.

B. Dispersion of alate aphids measured by Lloyd's patchiness index($\overset{*}{X}/\bar{X}$) in relation to mean number of aphids /cabbage plant.

CROP I




CROP II

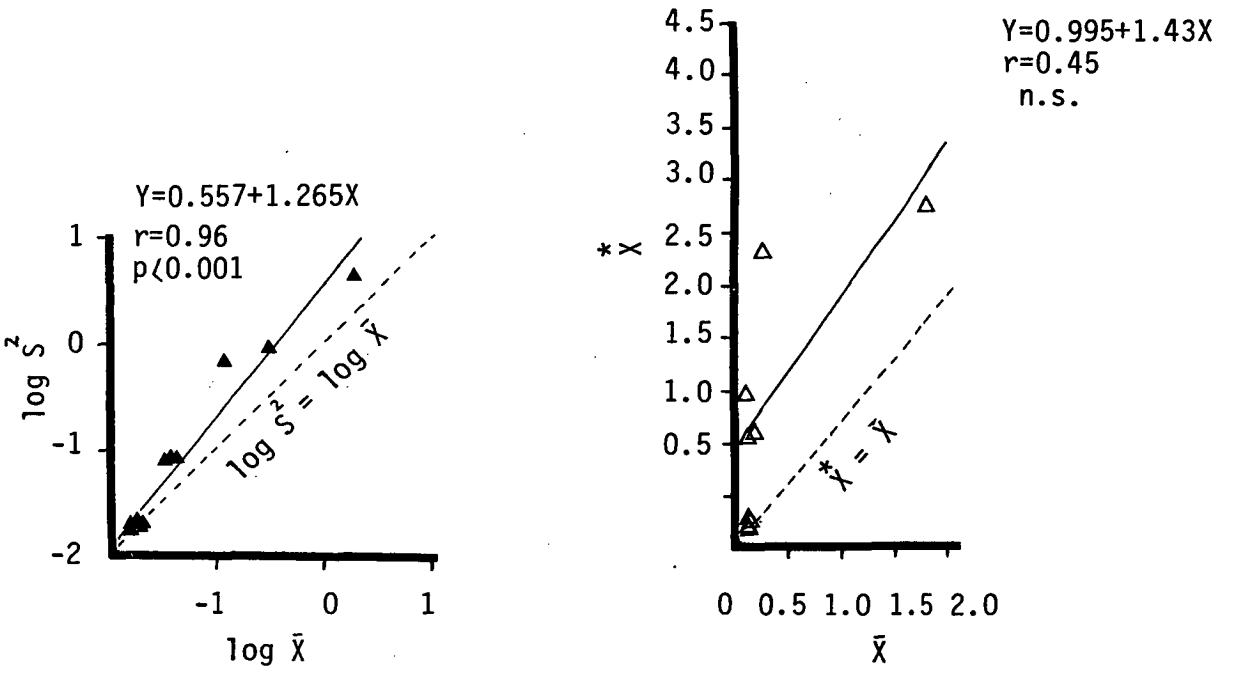



Fig. 4.39. Regression of log variance($\log \hat{S}^2$) on log mean($\log \bar{X}$) and mean crowding($\overset{*}{X}$) on mean density ($\bar{X}$) of alate cabbage aphids. Broken lines show linear tendency of relationship when $\hat{S}^2=\bar{X}$ or $\overset{*}{X}=\bar{X}$ (Poisson expectation).

Table 4.25 Indices of dispersion for populations of *B. brassicae* apterae (Crop I, 1982-83).

| Date of sampling | Mean | Variance/ Mean | Mean crowding | Lloyd's patchiness index | Green's coefficient of dispersion |
|---|---|---|---|---|---|
| | $(\bar{X})$ | $S^2/\bar{X}$ | $(\overset{*}{X})$ | $(\overset{*}{X}/\bar{X})$ | (Cx) |
| 22 Sep. | 0.22 | 1.05 | 0.27 | 1.22 | 0.05 |
| 29 Sep. | 0.87 | 1.68 | 1.55 | 1.77 | 0.02 |
| 6 Oct. | 0.18 | 2.53 | 1.71 | 9.48 | 0.17 |
| 13 Oct. | 4.87 | 2.56 | 6.43 | 1.32 | 0.06 |
| 20 Oct. | 2.12 | 13.52 | 14.64 | 6.90 | 0.11 |
| 27 Oct. | 2.98 | 14.03 | 16.01 | 5.37 | 0.10 |
| 3 Nov. | 4.38 | 17.11 | 20.49 | 4.68 | 0.07 |
| 10 Nov. | 4.33 | 12.30 | 15.63 | 3.61 | 0.05 |
| 17 Nov. | 1.01 | 4.58 | 4.59 | 4.54 | 0.07 |
| 24 Nov. | 3.24 | 20.19 | 22.43 | 6.92 | 0.11 |
| 1 Dec. | 0.29 | 3.98 | 3.27 | 11.28 | 0.20 |
| 8 Dec. | 2.46 | 17.67 | 19.13 | 7.77 | 0.20 |
| 15 Dec. | 0.88 | 26.57 | 26.47 | 30.07 | 0.61 |
| 22 Dec. | 6.39 | 26.64 | 32.03 | 5.01 | 0.07 |
| 29 Dec. | 3.66 | 154.51 | 157.17 | 42.94 | 0.77 |
| 5 Jan. | 12.66 | 94.07 | 105.73 | 8.35 | 0.13 |
| 12 Jan. | 2.90 | 30.47 | 32.37 | 11.16 | 0.19 |
| 19 Jan. | 17.07 | 162.36 | 178.43 | 10.45 | 0.25 |
| 26 Jan. | 12.61 | 165.05 | 185.34 | 14.70 | 0.28 |
| 2 Feb. | 34.87 | 209.51 | 243.38 | 6.72 | 0.08 |

Table 4.26 Indices of dispersion for populations of B.brassicae apterae (Crop II, 1983).

| Date of sampling | Mean | Variance/ Mean | Mean crowding | Lloyd's patchiness index | Green's coefficient of dispersion |
|---|---|---|---|---|---|
| | $(\bar{X})$ | $(S^2/\bar{X})$ | $(\overset{*}{X})$ | $(\overset{*}{X}/\bar{X})$ | (Cx) |
| 25 Mar. | 13.44 | 12.99 | 25.43 | 1.89 | 0.02 |
| 3 Apr. | 2.17 | 18.65 | 19.82 | 9.15 | 0.15 |
| 13 Apr. | 0.76 | 8.35 | 8.11 | 10.68 | 0.19 |
| 18 Apr. | 0.60 | 11.44 | 11.03 | 18.63 | 0.39 |
| 28 Apr. | 1.83 | 62.49 | 63.33 | 34.54 | 0.63 |
| 4 May | 0.39 | 14.43 | 13.82 | 35.61 | 0.01 |
| 18 May | 1.94 | 19.00 | 19.94 | 10.25 | 0.17 |
| 25 May | 0.72 | 6.86 | 6.52 | 9.02 | 0.15 |
| 2 Jun. | 3.80 | 25.35 | 28.14 | 7.14 | 0.12 |
| 8 Jun. | 2.37 | 10.43 | 11.80 | 4.97 | 0.07 |
| 15 Jun. | 1.80 | 9.13 | 9.92 | 5.52 | 0.09 |
| 22 Jun. | 1.06 | 21.08 | 21.14 | 20.03 | 0.35 |
| 29 Jun. | 5.57 | 38.12 | 42.69 | 7.65 | 0.12 |
| 6 Jul. | 6.35 | 49.03 | 54.38 | 8.56 | 0.14 |
| 13 Jul. | 0.85 | 7.69 | 7.54 | 8.85 | 0.15 |
| 20 Jul. | 8.70 | 177.44 | 185.14 | 21.27 | 0.38 |
| 27 Jul. | 0.41 | 7.44 | 6.85 | 16.82 | 0.31 |
| 3 Aug. | 7.81 | 72.06 | 78.87 | 10.09 | 0.18 |
| 10 Aug. | 1.28 | 18.88 | 19.16 | 15.0 | 0.30 |
| 18 Aug. | 20.56 | 182.77 | 202.32 | 9.84 | 0.11 |
| 25 Aug. | 3.55 | 49.40 | 51.95 | 14.63 | 0.25 |
| 1 Sep. | 26.85 | 186.67 | 212.52 | 7.91 | 0.13 |
| 15 Sep. | 1.79 | 60.13 | 60.91 | 34.02 | 0.62 |

in both crop seasons. Green's coefficient (Cx) also indicated that aphid populations were aggregated throughout the seasons (Cx>0.0). Significant relationships ($P<0.001$) were obtained when $S^2/\bar{X}$ values were regressed on mean density ($\bar{X}$) values in both seasons (Fig. 4.40 A).

All values of Lloyd's patchiness index were greater than 1.0 and described an aggregated dispersion in both crops. Figure 4.40 B shows the trends in patchiness relative to population densities in time. Temporal changes in patchiness were not related to population changes. Taylor's and Iwao's regressions fitted the data significantly ($P<0.001$, Fig. 4.41). However, the values obtained from the power law were much lower (1.92, 1.67) than the values of (7.83, 7.81) in crops I and II respectively.

### 4.3.7.2 Cabbage white butterfly

#### 4.3.7.2.1 Eggs

Seasonal trends in the dispersion of CWB eggs on cabbage crops are shown in Table 4.27. Dispersion changed throughout the season and ranged from uniform through random to aggregated. Populations were aggregated on 6 of 17 sampling dates however as the cabbage crop neared maturity the dispersion of eggs was found either random or aggregated. All indices had similar trends of dispersion. The $S^2/\bar{X}$ values when regressed on $\bar{X}$ values did not give a significant correlation (Fig. 4.42). Taylor's power law and Iwao's regression fitted the data significantly ($P<0.001$, Fig. 4.43). However, the correlation coefficient

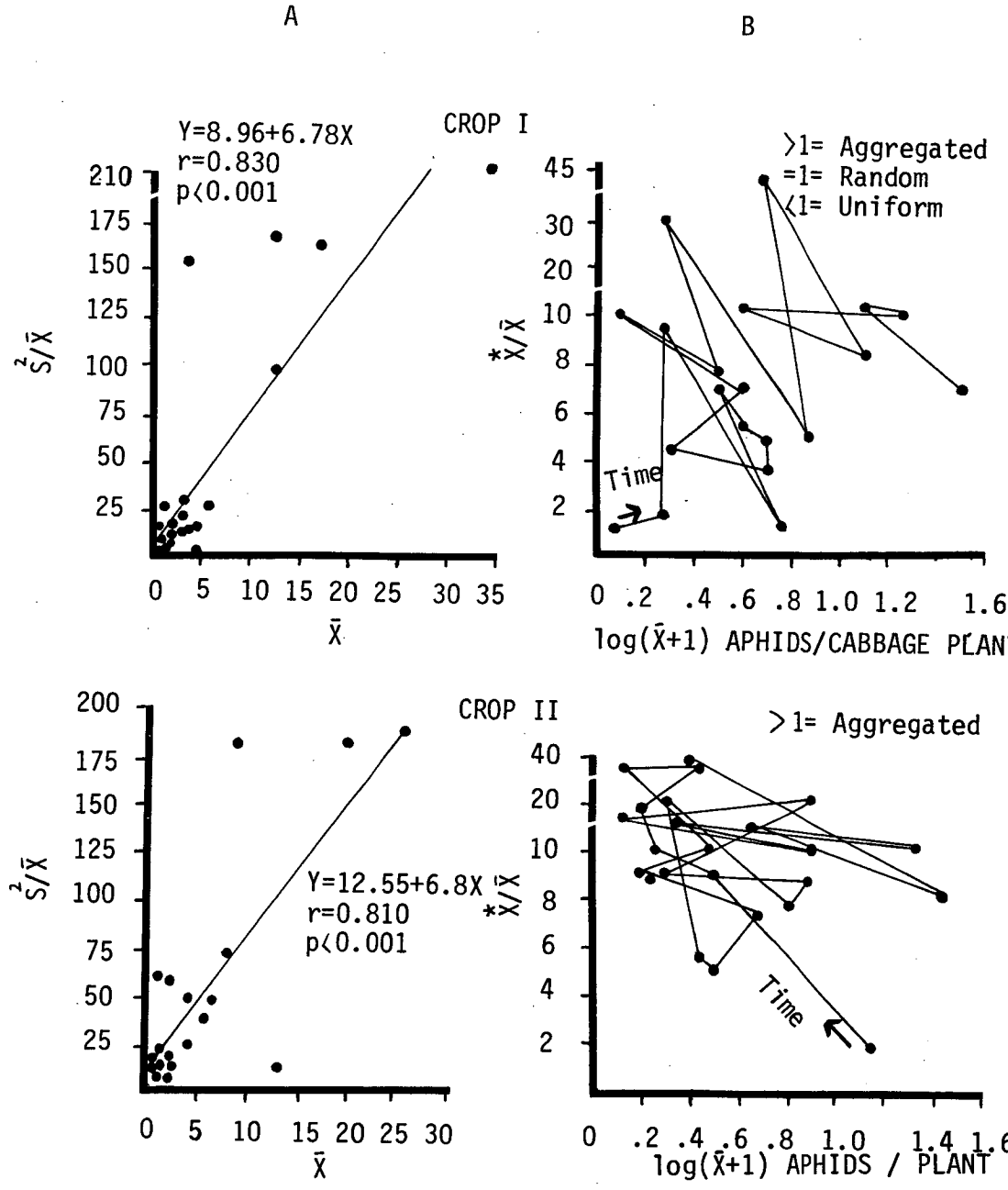



Fig. 4.40.(A) Relationship of variance/mean ratio ($\hat{S}/\bar{X}$) to mean density ($\bar{X}$) of cabbage aphid apterae.

(B) Dispersion of apterae aphids measured by Lloyd's patchiness index($\overset{*}{X}/\bar{X}$) in relation to mean number of aphids/ plant.

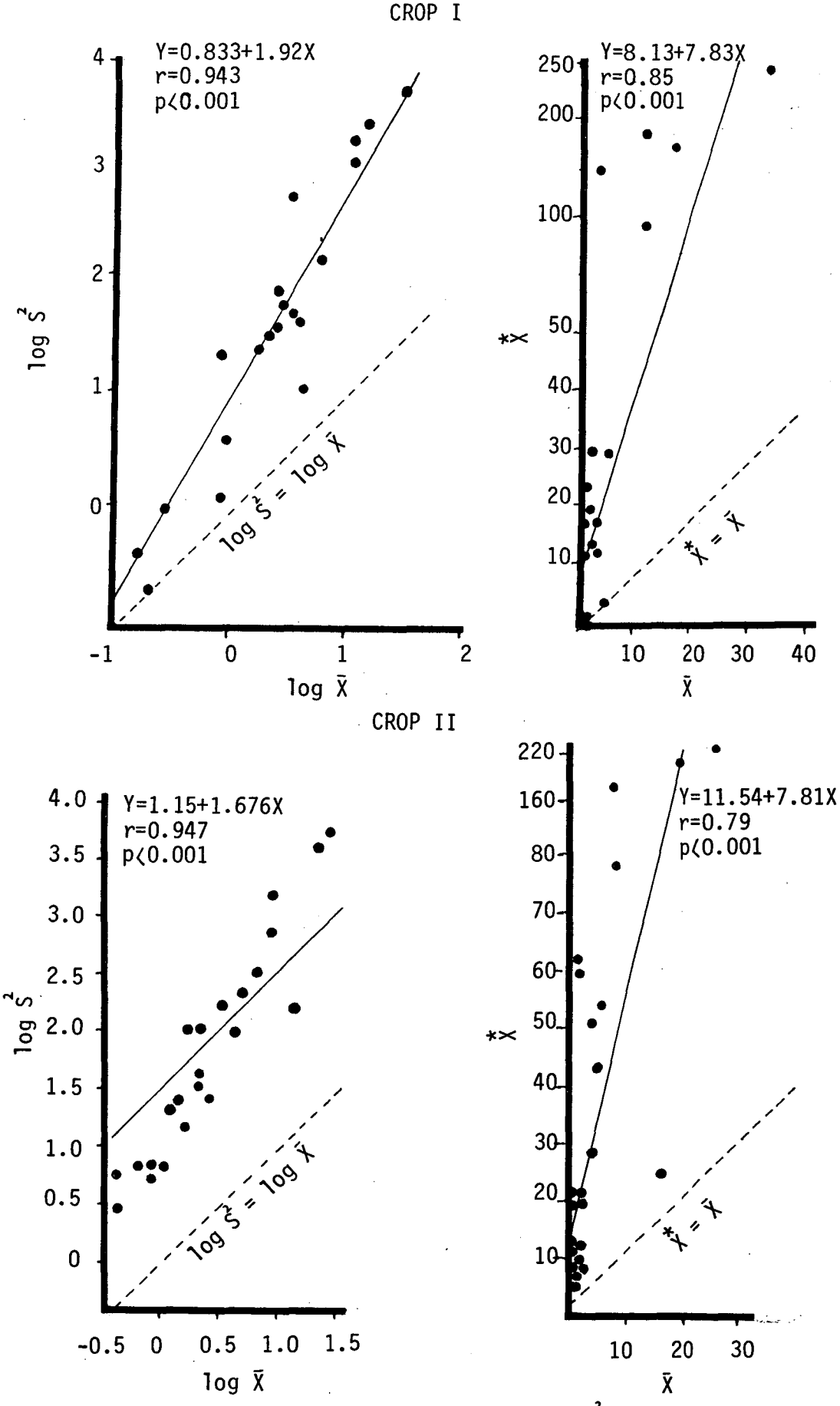



Fig. 4.41. Regression of log variance ($\log \hat{S}^2$) on log mean ($\log \bar{X}$) and mean crowding ($\overset{*}{X}$) on mean density ($\bar{X}$) of cabbage aphid apterae. Broken lines show linear tendency of relationship when $\hat{S}^2=\bar{X}$ or $\overset{*}{X}=\bar{X}$ (Poisson expectation).

Table 4.27 Indices of dispersion for the egg population of CWB (1982-83).

| Date of Sampling | Mean | Variance/ Mean | Mean crowding | Lloyd's patchiness index | Green's coefficient of dispersion |
|---|---|---|---|---|---|
| | $(\bar{X})$ | $(S^2/\bar{X})$ | $(\overset{*}{X})$ | $(\overset{*}{X}/\bar{X})$ | (Cx) |
| 15 Sep. | 0.02 | 1.00 | 0.02 | 1.00 | 0.00 |
| 22 Sep. | 0.77 | 0.42 | 0.19 | 0.25 | -0.01 |
| 29 Sep. | 1.57 | 0.64 | 1.21 | 0.77 | -0.004 |
| 6 Oct. | 1.96 | 1.73 | 2.69 | 1.37 | 0.006 |
| 13 Oct. | 1.51 | 0.87 | 1.38 | 0.91 | -0.001 |
| 20 Oct. | 0.94 | 1.34 | 1.28 | 1.36 | 0.00072 |
| 27 Oct. | 0.81 | 0.89 | 0.70 | 0.86 | -0.002 |
| 3 Nov. | 0.37 | 0.74 | 0.11 | 0.31 | -0.96 |
| 10 Nov. | 0.28 | 0.74 | 0.13 | 0.47 | -0.94 |
| 17 Nov. | 0.02 | 1.00 | 0.02 | 1.00 | 0.00 |
| 24 Nov. | 0.04 | 2.01 | 1.05 | 29.05 | 1.01 |
| 1 Dec. | 0.09 | 1.33 | 0.42 | 4.58 | 0.07 |
| 8 Dec. | 0.02 | 1.00 | 0.02 | 1.00 | 0.00 |
| 15 Dec. | 0.04 | 2.01 | 1.05 | 29.05 | 1.01 |
| 22 Dec. | 0.04 | 2.01 | 1.05 | 29.05 | 1.01 |
| 29 Dec. | 0.02 | 1.00 | 0.02 | 1.00 | 0.00 |
| 19 Jan. | 0.02 | 1.00 | 0.02 | 1.00 | 0.00 |

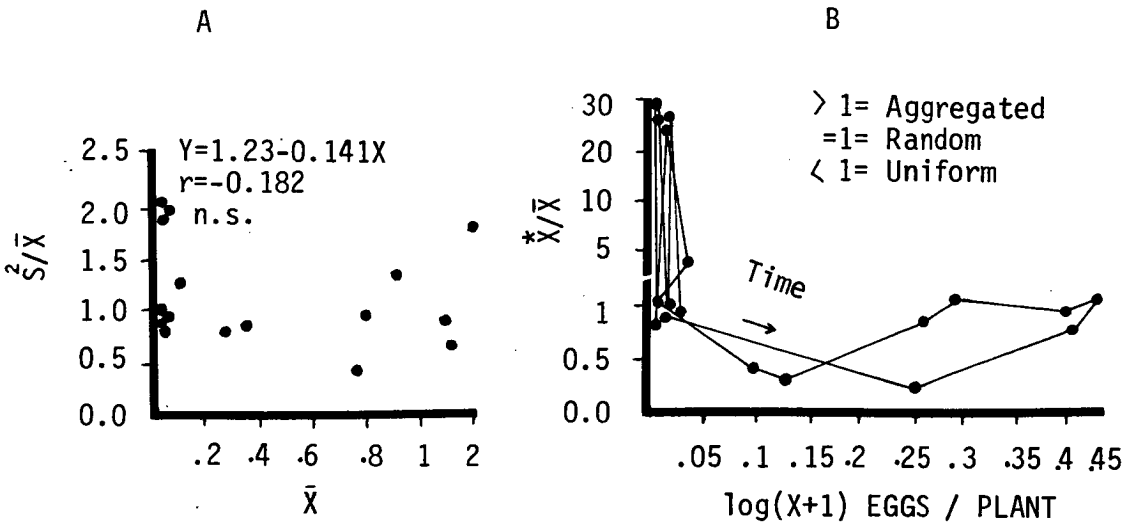



Fig. 4.42.A Relationship of variance/mean ratio($\hat{S}/\bar{X}$) to mean density ($\bar{X}$) of CWB eggs.

B Dispersion of CWB eggs measured by Lloyd's patchiness index($\overset{*}{X}/\bar{X}$) in relation to the mean number of eggs / plant.

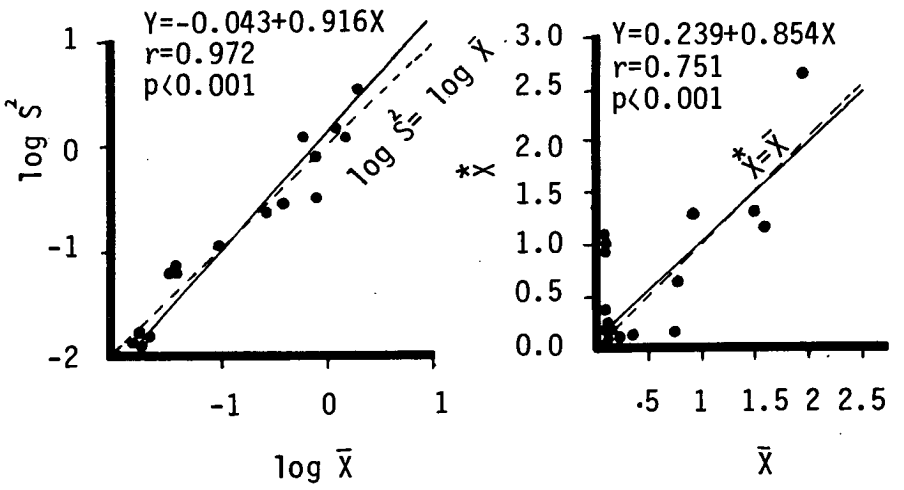



Fig.4.43. Regression of log variance(log $\hat{S}^2$) on log mean(log $\bar{X}$) and mean crowding($\overset{*}{X}/\bar{X}$) on mean density($\bar{X}$) of CWB eggs. Broken lines show linear tendency of relationship when $\hat{S}^2=\bar{X}$ or $\overset{*}{X}=\bar{X}$.

of the former (r=0.97) was stronger than that of the later (r=0.75).

4.3.7.2.2 Larvae

Field data of CWB larvae showed that larval dispersion had mixed trends in crop I and II. Populations were aggregated on 5 random on 7 and uniform on 15 of 27 sampling dates (Table 4.28). With the exception to the first sampling in crop I the larvae were dispersed uniformly and contracted to a random distribution as the crop approached maturity and the populations declined. Dispersion trends indicated by all indices were the same. There was no significant correlation between $S^2/\bar{X}$ ratio and the mean population densities in both crops (r=0.191, r=-0.229, Fig. 4.44 A). Lloyd´s patchiness indices were also independent of temporal population densities (Fig. 4.44 B).

Taylor´s power law fitted the population data in both crops (P<0.001, Fig. 4.45) but Iwao´s regression was only significant for crop I. The regression lines of Taylor´s power law were not different from the lines of Poisson expectation ($S^2=\bar{X}$) indicating random dispersion of CWB larvae in the cabbage crops.

4.3.7.3 Diamondback moth

4.3.7.3.1 Eggs

Trends in the dispersion of DM eggs in the cabbage crop are shown in Table 4.29. All dispersion indices indicated that eggs were aggregated. Green´s coefficient

Table 4.28 Indices of dispersion for population of CWB larvae (Crop I & II 1982-83).

| Date of sampling | Mean | Variance/ Mean | Mean crowding | Lloyd's patchiness index | Green's coefficient of dispersion |
|---|---|---|---|---|---|
| | ($\bar{X}$) | ($S^2/\bar{X}$) | ($\overset{*}{X}$) | ($\overset{*}{X}/\bar{X}$) | (Cx) |
| | | | Crop I | | |
| 22 Sep. | 0.02 | 1.00 | 0.02 | 1.00 | 0.00 |
| 29 Sep. | 0.04 | 0.97 | 0.01 | 0.18 | -0.30 |
| 6 Oct. | 0.13 | 0.88 | 0.01 | 0.07 | -0.02 |
| 13 Oct. | 0.65 | 0.47 | 0.12 | 0.19 | -0.02 |
| 20 Oct. | 0.39 | 0.82 | 0.21 | 0.53 | -0.009 |
| 27 Oct. | 0.33 | 0.91 | 0.25 | 0.74 | -0.005 |
| 3 Nov. | 0.30 | 0.85 | 0.14 | 0.48 | -0.01 |
| 10 Nov. | 0.61 | 0.52 | 0.13 | 0.21 | -0.02 |
| 17 Nov. | 0.53 | 0.48 | 0.01 | 0.01 | -0.02 |
| 24 Nov. | 0.28 | 1.01 | 0.28 | 1.03 | -0.0005 |
| 1 Dec. | 0.69 | 0.76 | 0.45 | 0.65 | -0.006 |
| 8 Dec. | 1.69 | 1.92 | 2.69 | 1.59 | 0.030 |
| 15 Dec. | 0.30 | 0.72 | 0.01 | 0.04 | -0.02 |
| 22 Dec. | 0.04 | 2.01 | 1.05 | 29.05 | 1.01 |
| 29 Dec. | 0.02 | 1.00 | 0.02 | 1.00 | 0.00 |
| 5 Jan. | 0.09 | 0.92 | 0.02 | 0.16 | 0.03 |
| 19 Jan. | 0.02 | 1.00 | 0.02 | 1.00 | 0.00 |

Table 4.28 (continued)

| Date of sampling | Mean ($\bar{X}$) | Variance/ Mean ($S^2/\bar{X}$) | Mean crowding ($\overset{*}{X}$) | Lloyd's patchiness index ($\overset{*}{X}/\bar{X}$) | Green's coefficient of dispersion (Cx) |
|---|---|---|---|---|---|
| | | | Crop II | | |
| 25 Mar. | 0.09 | 0.93 | 0.02 | 0.24 | -0.007 |
| 3 Apr. | 0.09 | 0.93 | 0.02 | 0.24 | -0.007 |
| 13 Apr. | 0.33 | 1.01 | 0.34 | 1.03 | 0.0002 |
| 18 Apr. | 0.11 | 0.90 | 0.01 | 0.09 | -0.009 |
| 28 Apr. | 0.13 | 0.88 | 0.01 | 0.07 | -0.009 |
| 4 May | 0.07 | 1.45 | 0.52 | 7.01 | 0.07 |
| 18 May | 0.04 | 2.01 | 1.05 | 29.00 | 0.34 |
| 25 May | 0.02 | 1.00 | 0.02 | 1.00 | 0.00 |
| 8 Jun. | 0.02 | 1.00 | 0.02 | 1.00 | 0.00 |
| 22 Jun. | 0.02 | 1.00 | 0.02 | 1.00 | 0.00 |

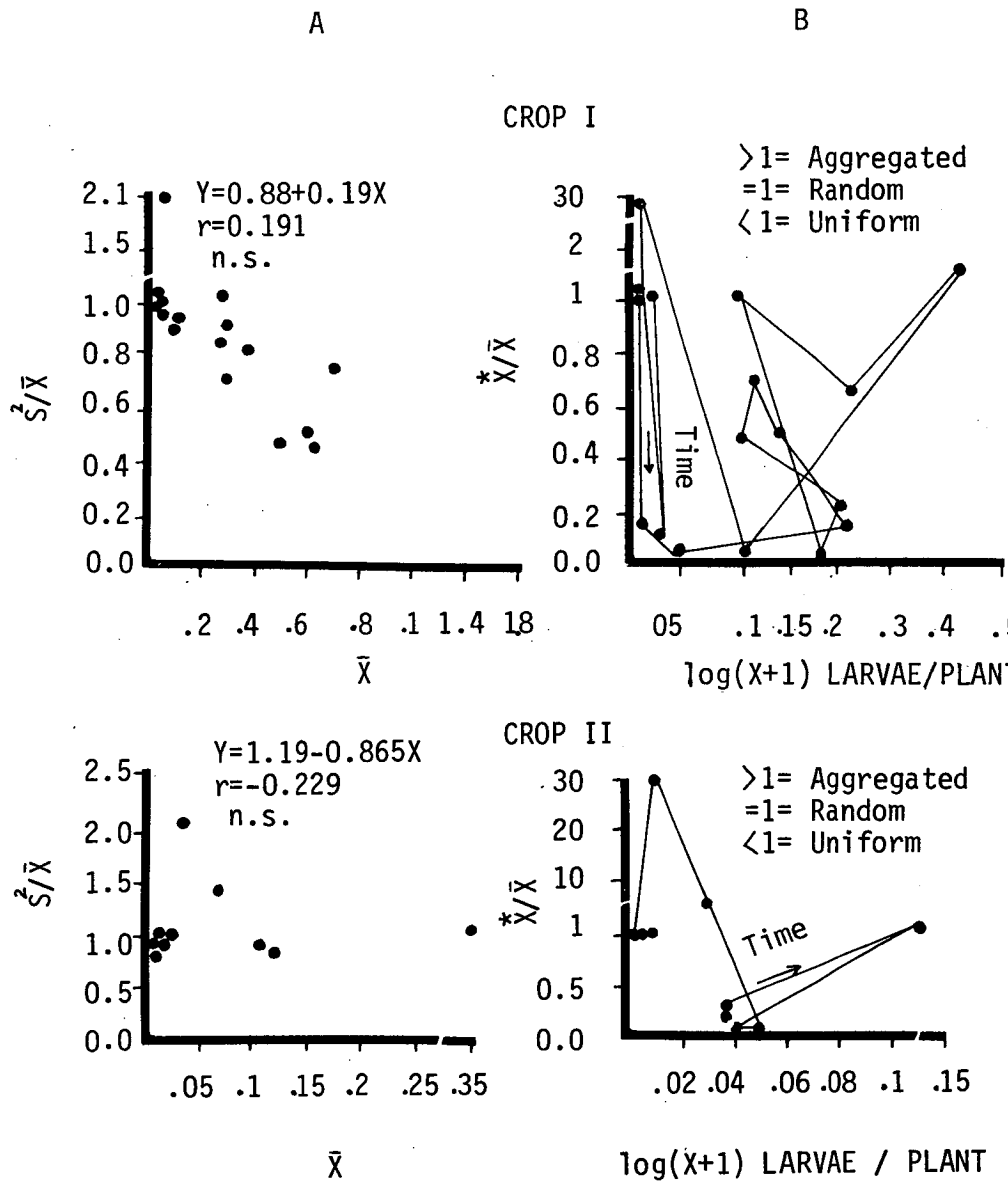



FIg. 4.44.A. Relationship of variance/mean ratio ($\hat{S}^2/\bar{X}$) to mean density ($\bar{X}$) of CWB larvae.

B. Dispersion trends of larvae measured by Lloyd's patchiness index ($\overset{*}{X}/\bar{X}$) in relation to mean number of larvae / plant.

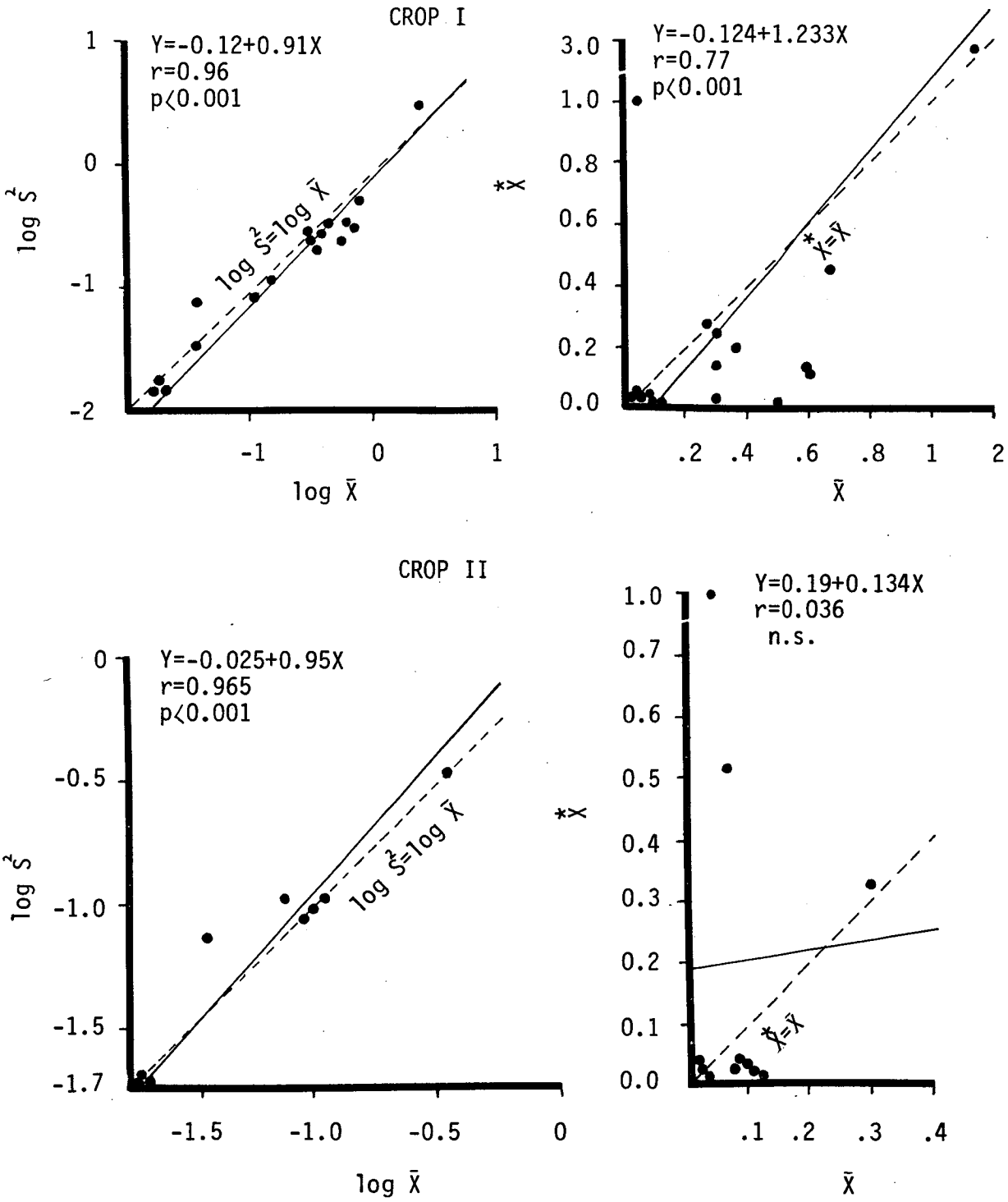



Fig. 4.45. Regression of log variance (log $\hat{S}^2$) on log mean (log $\bar{X}$) and mean crowding ($\overset{*}{X}$) on mean density ($\bar{X}$) of CWB larvae. Broken lines show linear tendency of relationship when $\hat{S}^2=\bar{X}$ or $\overset{*}{X}=\bar{X}$.

Table 4.29 Indices of dispersion for the egg population of DM (1982).

| Date of sampling | Mean $\bar{X}$ | Variance/ Mean $(S^2/\bar{X})$ | Mean crowding $(\overset{*}{X})$ | Lloyd's patchiness Index $(\overset{*}{X}/\bar{X})$ | Green's coefficient of dispersion (Cx) |
|---|---|---|---|---|---|
| 20 Oct. | 0.18 | 5.08 | 4.26 | 23.05 | 0.45 |
| 27 Oct. | 0.14 | 3.94 | 3.08 | 21.70 | 0.42 |
| 3 Nov. | 0.05 | 3.01 | 2.06 | 37.54 | 1.00 |
| 10 Nov. | 0.11 | 2.28 | 1.39 | 12.63 | 0.25 |
| 17 Nov. | 0.18 | 5.11 | 4.29 | 23.21 | 0.45 |

was consistently greater than 0.0 and only on one occasion approached unity. The relationship of $S^2/\bar{X}$ ratio to $\bar{X}$ was not significant despite a strong and positive value of the correlation coefficient (r=0.841, Fig. 4.46). Lloyd's patchiness index was not related to the population densities as the time progressed. Taylor's regression described the dispersion of eggs better than Iwao's regression (Fig. 4.47).

4.3.7.3.2 Larvae

Dispersion of DM larval populations was either uniform or aggregated. It was aggregated on 10 random on 2 and uniform on 11 of 23 sampling occasions. In contrast, the mean crowding indices showed aggregated distribution only on 2 of the 23 dates and a uniform distribution on the remainder (Table 4.30). Lloyd's index described similar trends as the $S^2/\bar{X}$ ratios and Green's coefficient, with a uniform distribution on 11 occasions. Correlations between $S^2/\bar{X}$ and $\bar{X}$ were not significant in crops I and II (r=-0.382, r=-0.015 respectively, Fig. 4.48 A). However, the data indicate that at higher densities the populations were either uniform or random and became aggregated as the densities decreased (4.48 B). Taylor's and Iwao's measures gave significant regressions however, Taylor's regressions were stronger ($P<0.001$) than the Iwao's regressions ($P<0.05$ and $P<0.01$ in crop I and II respectively, Fig. 4.49).

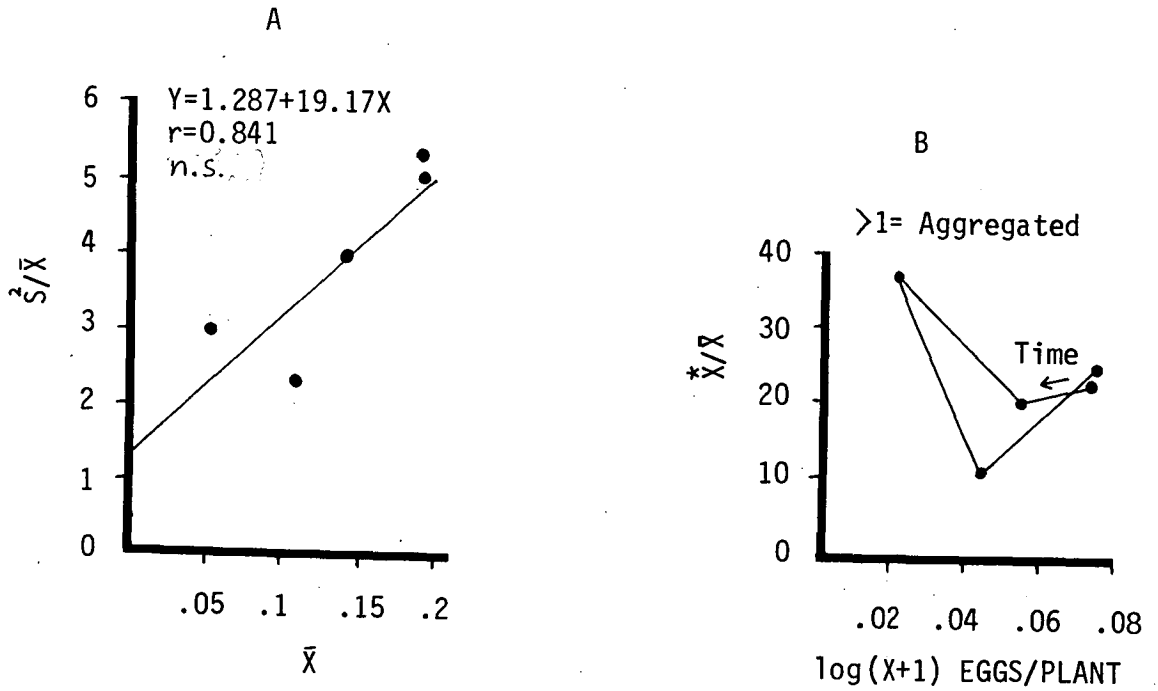



Fig. 4.46.A. Relationship of variance/mean ratio ($\hat{S}^2/\bar{X}$) to mean density ($\bar{X}$) of DM eggs.

B. Dispersion trends of eggs measured by Lloyd's patchiness index ($\overset{*}{X}/\bar{X}$) in relation to mean number of eggs / plant.

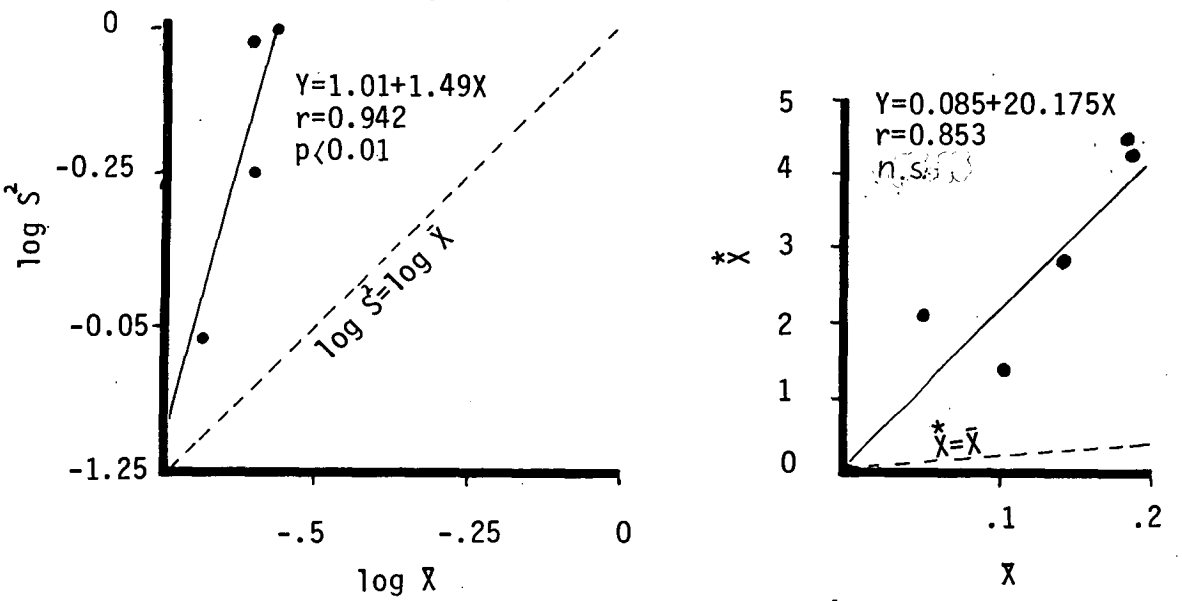



Fig. 4.47. Regression of log variance (log $\hat{S}^2$) on log mean ($\bar{X}$) and mean crowding ($\overset{*}{X}$) on mean density ($\bar{X}$) of DM eggs. Broken lines show linear tendency of relationship when $\hat{S}^2=\bar{X}$ or $\overset{*}{X}=\bar{X}$

Table 4.30 Indices of dispersion for the population of DM larvae (Crop I & II, 1982-83)

| Date of sampling | Mean | Variance/ Mean | Mean crowding | Lloyd's patchiness index | Green's coefficient of dispersion |
|---|---|---|---|---|---|
| | $(\bar{X})$ | $(S^2/\bar{X})$ | $(\overset{*}{X})$ | $(\overset{*}{X}/\bar{X})$ | (Cx) |
| | | | Crop I | | |
| 20 Oct. | 0.09 | 1.79 | 0.88 | 9.75 | 0.20 |
| 27 Oct. | 0.31 | 0.94 | 0.25 | 0.81 | -0.003 |
| 3 Nov. | 0.52 | 1.07 | 0.59 | 1.14 | 0.003 |
| 10 Nov. | 0.96 | 0.59 | 0.55 | 0.57 | -0.007 |
| 17 Nov. | 0.93 | 1.01 | 1.93 | 2.08 | 0.0001 |
| 24 Nov. | 0.52 | 0.64 | 0.15 | 0.30 | -0.013 |
| 1 Dec. | 0.24 | 0.93 | 0.17 | 0.70 | -0.005 |
| 8 Dec. | 0.37 | 1.97 | 1.34 | 3.61 | 0.12 |
| 15 Dec. | 0.11 | 0.90 | 0.01 | 0.10 | -0.02 |
| 22 Dec. | 0.24 | 1.25 | 0.49 | 2.02 | 0.02 |
| 29 Dec. | 0.15 | 0.87 | 0.02 | 0.11 | -0.02 |
| 5 Jan. | 0.31 | 0.94 | 0.25 | 0.81 | -0.003 |
| 12 Jan. | 0.11 | 1.24 | 0.35 | 3.19 | 0.49 |
| 19 Jan. | 0.07 | 1.45 | 0.52 | 7.01 | 0.15 |
| 2 Feb. | 0.09 | 0.94 | 0.03 | 0.28 | -0.02 |
| | | | Crop II | | |
| 25 Mar. | 0.56 | 1.40 | 0.96 | 1.72 | 0.01 |
| 3 Apr. | 0.63 | 1.28 | 0.91 | 1.43 | 0.008 |
| 13 Apr. | 0.91 | 0.80 | 0.71 | 0.78 | -0.004 |
| 18 Apr. | 0.33 | 0.90 | 0.23 | 0.69 | -0.005 |
| 28 Apr. | 0.06 | 0.96 | 0.02 | 0.27 | -0.04 |
| 4 May | 0.09 | 1.33 | 0.42 | 4.58 | 0.07 |
| 11 May | 0.02 | 1.00 | 0.02 | 1.00 | 0.00 |
| 18 May | 0.02 | 1.00 | 0.02 | 1.00 | 0.00 |

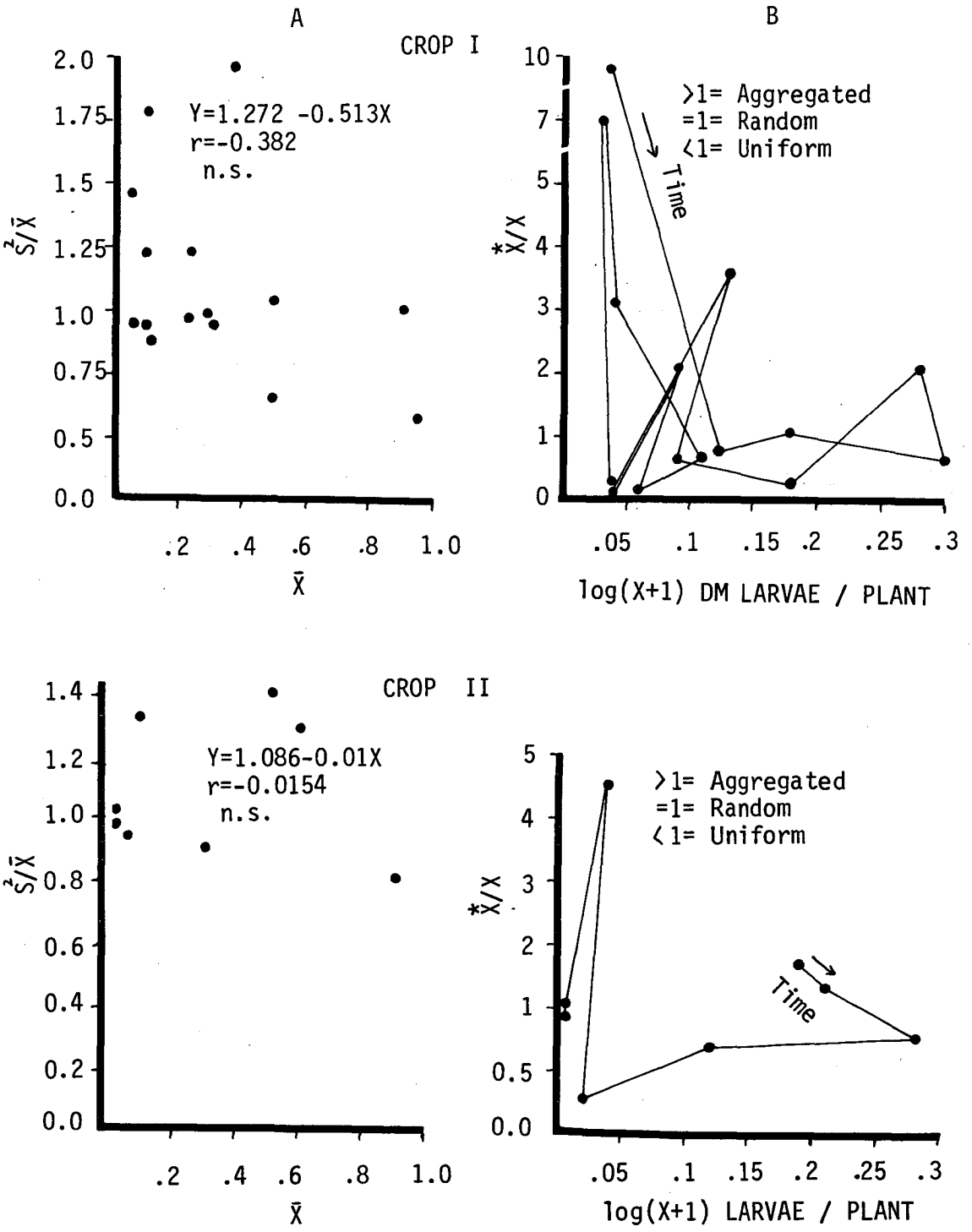



Fig. 4.48.A. Relationship of variance/mean ratio ($S^2/\bar{X}$) to mean density ($\bar{X}$) of DM larvae.

B. Dispersion trends of larvae measured by Lloyd's patchiness index ($\overset{*}{X}/\bar{X}$) in relation to mean number of larvae / plant.

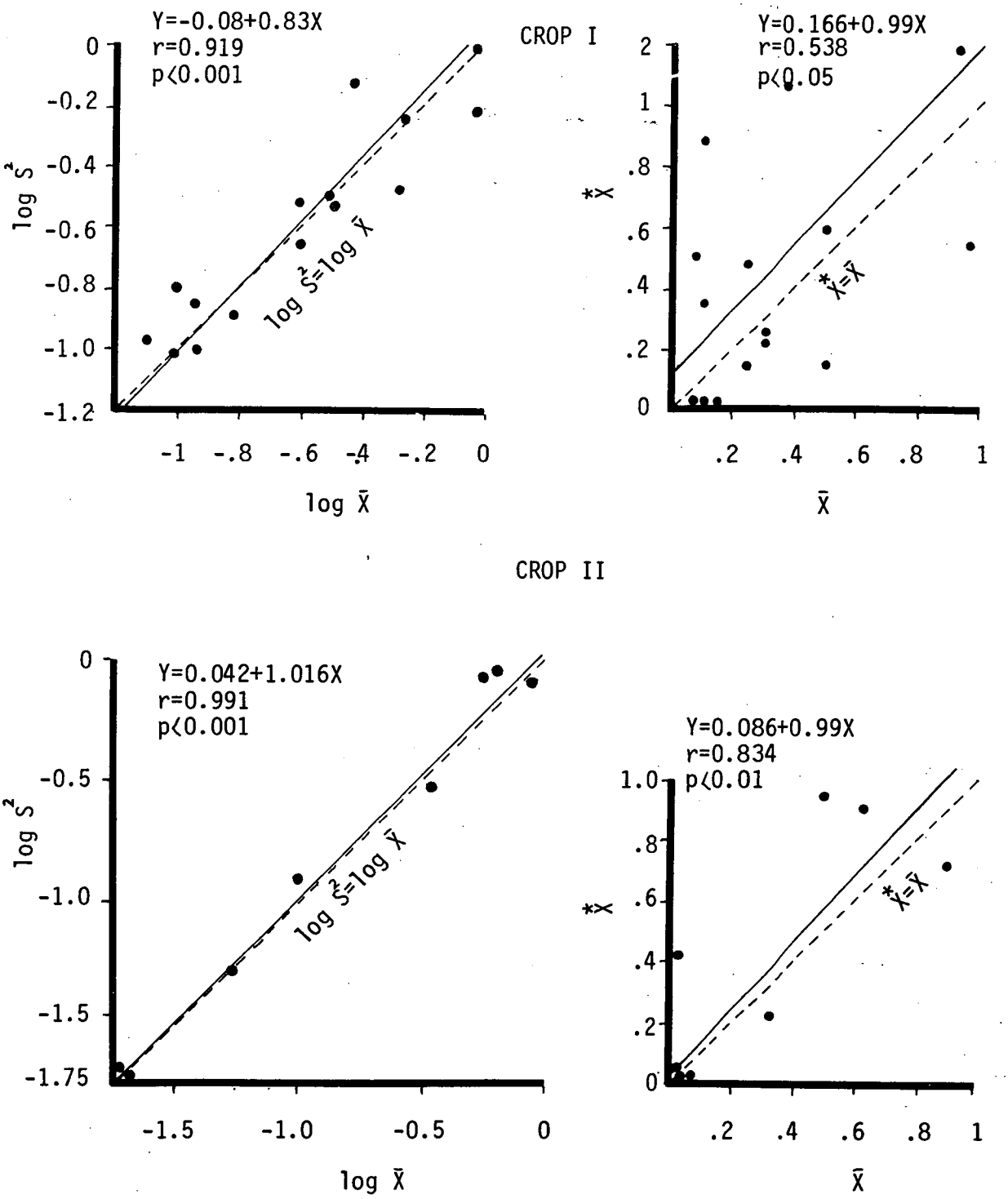



Fig. 4.49. Regression of log variance($\log \hat{S}^2$) on log mean($\log \bar{X}$) and mean crowding($\overset{*}{X}/\bar{X}$) on mean density($\bar{X}$) of DM larvae. Broken lines show linear tendency of relationship when $\hat{S}^2=\bar{X}$ or $\overset{*}{X}=\bar{X}$.

4.3.7.3.3 Pupae

Dispersion patterns of DM pupae in cabbage crop as expressed by different indices are shown in Table 4.31. The dispersion was aggregated on 7 random on 1 and uniform on 5 of 13 sampling occasions. In crop II the corresponding frequency of dispersion patterns numbered 3, 2 and 1 for uniform, random and aggregated patterns respectively. Lloyd's and Green's indices were consistent with the $S^2/\bar{X}$ but the mean crowding index differed indicating a uniform distribution with the exception of 1 sampling occasion in each crop. Correlations between $S^2/\bar{X}$ and $\bar{X}$ were not significant in both crops (Fig. 4.50 A). Lloyd's indices did not correspond to density increases in crop I, however, in crop II there was an indication that relatively higher densities occured with uniform distributions ($\overset{*}{X}/\bar{X}<1$, Fig. 4.50 B).

Taylor's regression fitted the data significantly in crop I ($P<0.001$) and in crop II ($P<0.01$). In both crops, the regression lines were not significantly different to that of a Poisson ($S^2=\bar{X}$, b=1). Iwao's regression was not a significant fit to the data (Fig. 4.51).

The overall comparison of different dispersion and regression indices employed in this study for measuring the population distribution of subject pest species are presented in Table 4.32.

Table 4.31 Indices of dispersion for the population of DM pupae (Crop I & II, 1982-83).

| Date of sampling | Mean | Variance/ Mean | Mean crowding | Lloyd's patchiness index | Green's coefficient of dispersion |
|---|---|---|---|---|---|
| | ($\bar{X}$) | ($S^2/\bar{X}$) | ($\overset{*}{X}$) | ($\overset{*}{X}/\bar{X}$) | (Cx) |
| | | | Crop I | | |
| 10 Nov. | 0.50 | 0.66 | 0.16 | 0.32 | -0.01 |
| 17 Nov. | 0.31 | 1.42 | 0.73 | 2.34 | 0.03 |
| 24 Nov. | 0.43 | 1.12 | 0.53 | 1.28 | 0.005 |
| 1 Dec. | 0.33 | 0.79 | 0.13 | 0.36 | -0.01 |
| 8 Dec. | 0.11 | 0.90 | 0.01 | 0.10 | -0.02 |
| 15 Dec. | 0.17 | 0.84 | 0.01 | 0.04 | -0.02 |
| 22 Dec. | 0.22 | 1.30 | 0.52 | 2.35 | 0.03 |
| 29 Dec. | 0.09 | 1.34 | 0.43 | 4.69 | 0.09 |
| 5 Jan. | 0.17 | 1.07 | 0.24 | 1.42 | 0.008 |
| 12 Jan. | 0.35 | 3.02 | 2.37 | 6.75 | 0.11 |
| 19 Jan. | 0.19 | 0.83 | 0.02 | 0.08 | -0.01 |
| 26 Jan. | 0.02 | 1.00 | 0.02 | 1.00 | 0.00 |
| 2 Feb. | 0.13 | 1.17 | 0.30 | 2.30 | 0.02 |
| | | | Crop II | | |
| 13 Apr. | 0.17 | 0.85 | 0.02 | 0.10 | -0.02 |
| 18 Apr. | 0.13 | 0.89 | 0.01 | 0.09 | -0.02 |
| 28 Apr. | 0.52 | 0.71 | 0.23 | 0.43 | -0.01 |
| 11 May | 0.02 | 1.00 | 0.02 | 1.00 | 0.00 |
| 18 May | 0.02 | 1.00 | 0.02 | 1.00 | 0.00 |
| 25 May | 0.04 | 2.01 | 1.05 | 29.05 | 1.01 |

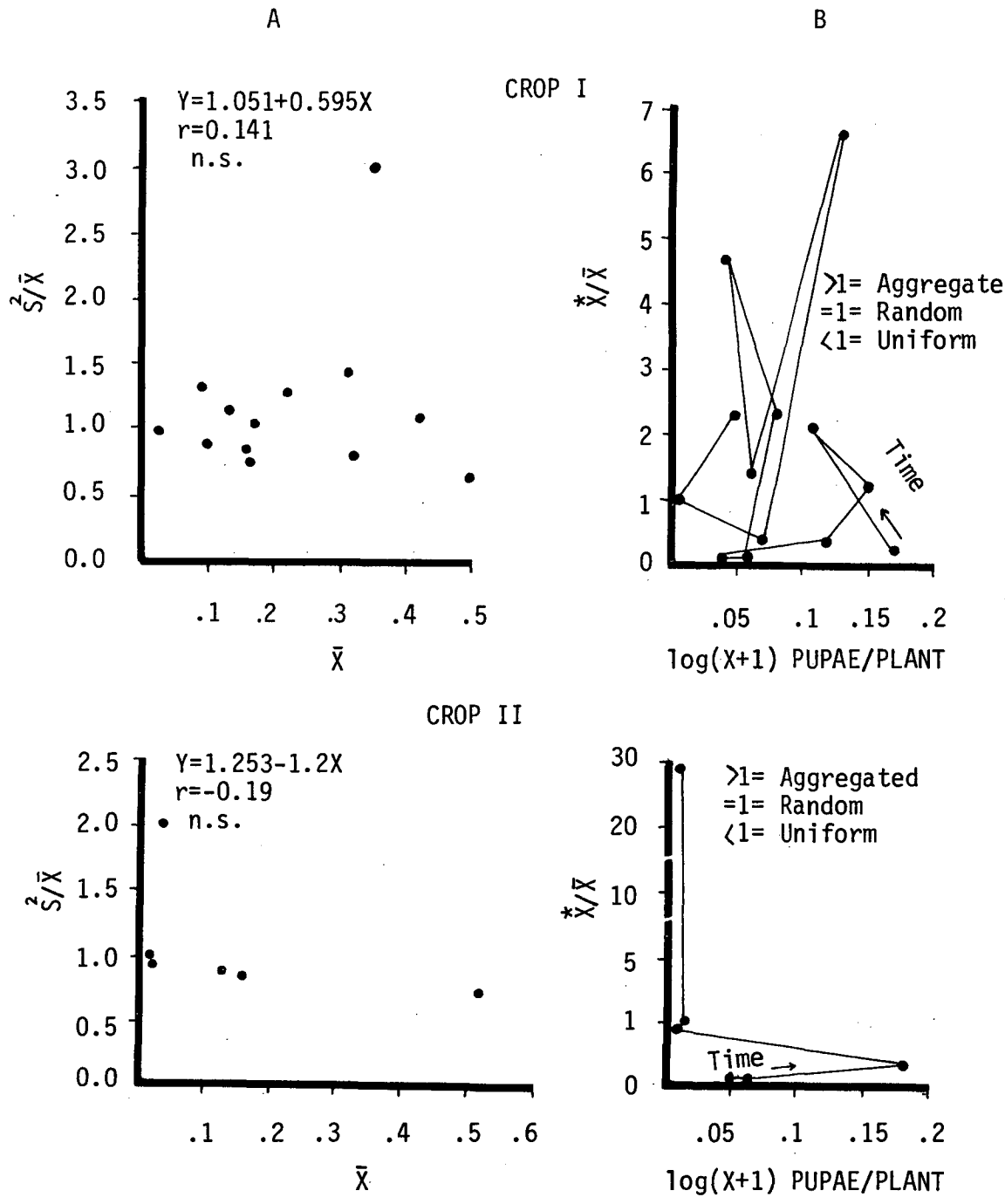



Fig. 4.50.A. Relationship of variance/mean ratio ($S^2/\bar{X}$) to mean density ($\bar{X}$) of DM pupae on cabbage plants.

B. Dispersion trends of pupae measured by Lloyd's patchiness index ($*\bar{X}/\bar{X}$) in relation to mean number of pupae / plant.

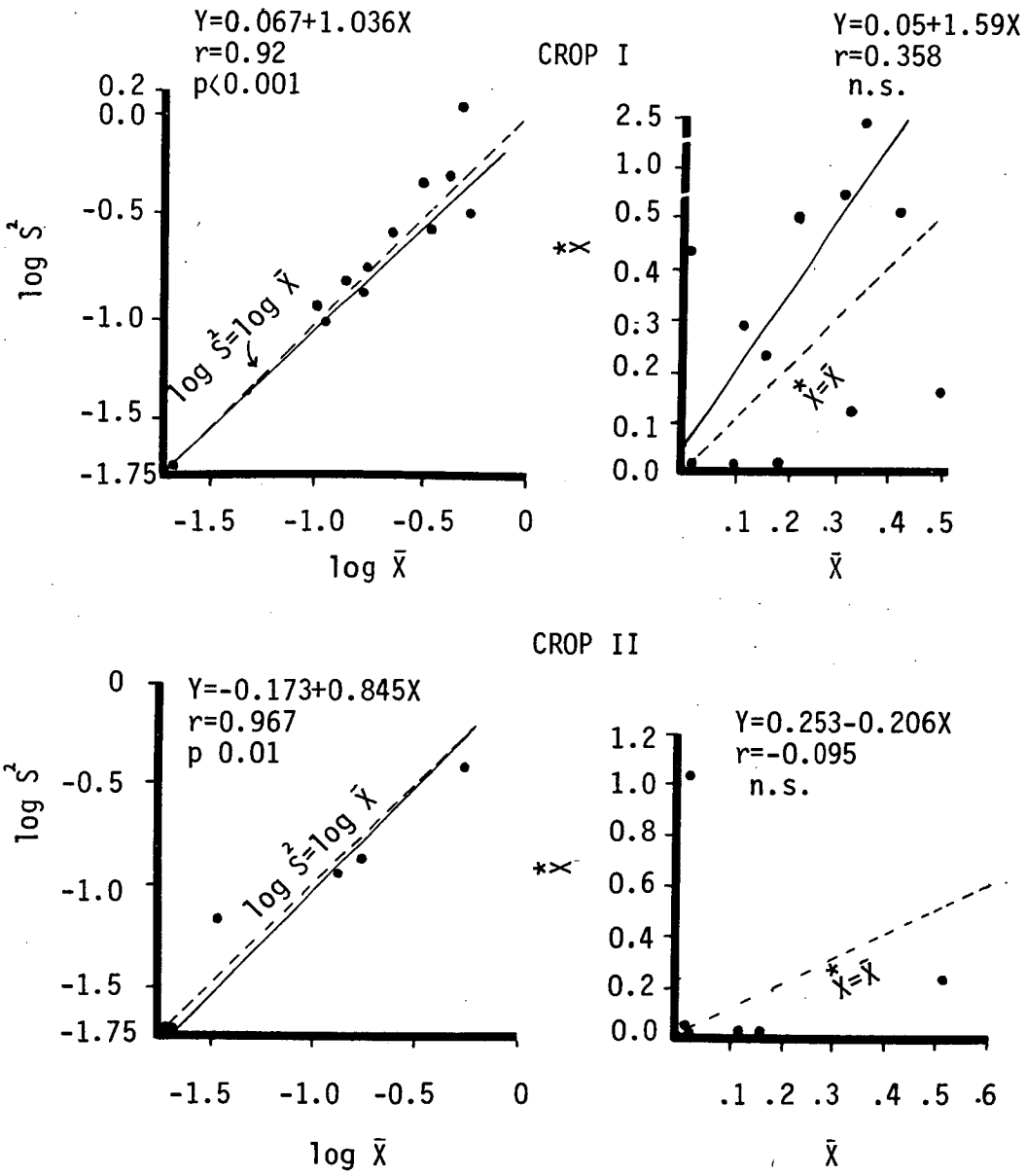



Fig. 4.51. Regression of log variance ($\log \hat{S}^2$) on log mean ($\log \bar{X}$) and mean crowding ($\overset{*}{X}/\bar{X}$) on mean density ($\bar{X}$) of DM pupae. Broken lines show linear tendency of relationship when $\hat{S}^2=\bar{X}$ or $\overset{*}{X}=\bar{X}$.

Table 4.32 Comparison of spatial dispersion and regression indices for the stages of three cabbage pests populations at S.J.F. College cabbage plots (1982-83).

| Pest species and stage | Crop No. | Aggregated populations in dispersion indices (%) | | | | Correlation coefficient and significance of regression indices | | |
|---|---|---|---|---|---|---|---|---|
| | | $S^2/\bar{X}$ | $\overset{*}{X}$ | $\overset{*}{X}/\bar{X}$ | Cx | $\frac{S^2/\bar{X}}{\bar{X}}$ | Taylor | Iwao |
| Cabbage aphid | | | | | | | | |
| Alate | I | 85 | 62 | 85 | 85 | 0.552 ** | 0.806 *** | 0.60 * |
| | II | 55 | 55 | 55 | 55 | 0.153 | 0.781 *** | 0.455 |
| Apterae | I | 100 | 95 | 100 | 100 | 0.830 *** | 0.943 *** | 0.850 *** |
| | II | 100 | 100 | 100 | 100 | 0.810 *** | 0.947 *** | 0.845 *** |
| CWB | | | | | | | | |
| Eggs | I | 35 | 41 | 35 | 41 | -0.182 | 0.972 *** | 0.751 *** |
| | II | - | - | - | - | - | - | - |
| Larvae | 1 | 17 | 11 | 17 | 17 | 0.191 | 0.962 *** | 0.770 *** |
| | II | 30 | 10 | 30 | 30 | -0.229 | 0.965 *** | 0.036 |
| DM | | | | | | | | |
| Eggs | I | 100 | 100 | 100 | 100 | 0.841 | 0.942 * | 0.853 |
| | II | - | - | - | - | - | - | - |
| Larvae | I | 46 | 13 | 46 | 46 | -0.382 | 0.919 *** | 0.538 ** |
| | II | 37 | 0 | 37 | 37 | -0.0154 | 0.991 *** | 0.834 ** |
| Pupae | I | 53 | 7 | 53 | 53 | 0.141 | 0.920 *** | 0.358 |
| | II | 16 | 16 | 16 | 16 | -0.190 | 0.967 ** | -0.095 |

Abbreviated Symbols :
Crop I = Summer crop ; Crop II = Winter crop ; $S^2/\bar{X}$ = Variance/mean
$\overset{*}{X}$ = mean crowding; $\overset{*}{X}/\bar{X}$ = Lloyd's patchiness index;
Cx= Green's coefficient of dispersion;
Taylor = Log variance($S^2$) on log mean ($\bar{X}$);Iwao : Mean crowding ($\overset{*}{X}$) on mean ($\bar{X}$).
* = P<0.05; ** = P<0.01; *** = P<0.001; n.s. = not significant (P>0.05)

## 4.4 Discussion

This investigation documents the involvement of a number of biotic and abiotic factors which influenced the efficiency of population sampling methods, seasonal abundance and behavioural ecology of insect pests of cabbage in Tasmania.

### 4.4.1 Efficiency of sampling methods

Despite the fact that less time was spent in the ordinal coding method, direct counting or *in situ* examination of the same plants in time gave a more informative and reliable appreciation of both insect numbers relative to the growth and phenology of cabbage plants. The direct counting method was also adopted by Hughes (1963) and Wilson *et al*. (1983) for population studies of CA ; by Harcourt (1966) and Dempster (1967) for CWB immature stages ; and by Hamilton (1979) for CWB and DM larvae and pupae. In contrast, Banks (1954) preferred the ordinal coding system for population estimates of *Aphis fabae* on bean. However, Strickland (1957) argued that ordinal class numbers do not give reliable figures for analysis though this difficulty can be overcome by subsampling each rank and proportionally weighting the frequency data.

One limitation of direct counting, noted in this evaluation, was that relatively less reliable estimates of adult butterflies and DM egg populations were obtained for the time involved. Similarly, Goodwin (1976) regarded direct counting of DM eggs as a time consuming and

inefficient sampling method.

In this investigation, the selection of inner rows within cabbage plots for sampling gave more accurate counts without edge effects. The lack of edge or directional effect is consistent with the results for counts of immature stages of DM by Harcourt (1961 b).

Under natural field conditions it was important to compare the efficiency of more than one sampling method to obtain the most reliable and cost effective estimates (e.g. Southwood, 1966). As evidenced in this investigation, no single method could absolutely satisfy these standards for sampling individual stages of all pest species. Nevertheless, all immature stages were best sampled by direct counting while trapping techniques were effective in sampling the insects in flight. Other methods were not necessarily related to pest infestation levels on crop plants.

The efficiency of Moericke traps for alate aphids is attributed to the aphid's attraction to yellow colour (Moericke, 1955; Kennedy and Stroyan, 1959). However, the lack of consistency in the trends of aphids recorded in traps and those counted on plants suggests that Moericke traps did not reliably reflect the actual abundance of alate aphids on crop plants. Similarly, sticky traps were not effective for sampling alate aphids and the reliability of this trapping technique to sample CA populations in broccoli crop was also questioned by Trumble et al. (1982). In contrast, Lamb and Lowe (1967) found a positive relationship between CA alate production

on plants and alate numbers on sticky traps.

This investigation revealed that sticky traps may effectively be employed to monitor field parasitism of aphid populations as the trends in the catches of the parasitoid, D. rapae, on traps were consistent with aphid parasitism levels on plants allowing a 1-2 week lag. Similar efficiency of sticky traps for parasitism was reported by Chua (1977) in population studies of CA in Brussel's sprouts.

Zoecon pheromone trap catches of DM moths reliably forecasted trends in larval population on plants 14 days later. Furthermore, the agreement between the moth catches within and outside of cabbage crop suggested that this trapping device may reliably be used to predict larval populations of DM in cropping systems (see also Baker et al., 1982).

Considering the relative efficiency of these trapping methods, the results suggest that such methods with the exception of Moericke traps could be effectively used in conjunction with the direct counting method to monitor and predict important changes in the population structure of cabbage insect pests.

### 4.4.2 Seasonal abundance of pests and their natural enemies

Populations of CA persisted in cabbage crops throughout the year, though lower temperatures in winter inhibited alate production and dispersal. Generally, the growth of all pest species was determined primarily by

favourable temperature (i.e. 10-22°C) which inturn favoured their pest status.

The flight of alate immigrants occured during spring-early autumn which played a major role in infesting the cabbage crops. The parthenogenetic (anholocyclic) gregarious reproduction of this species was particularly damaging to newly established seedlings and, when allowed to persist, destroyed the growing apical tissues which resulted in stunted plants. Furthermore, the sheltered aphid colonies during head formation stage contaminate the harvestable part of the plant. These features clearly indicate the pest status of this species under Tasmanian conditions. The numbers of alate forms relative to density of apterous aphids indicated that alate formation was density-dependent phenomenon and this is consistent with the findings of Kawada (1964) and Pollard (1969). In addition to temperature, the only other weather components observed to markedly affect aphid population, were precipitation and relative humidity. Relative humidity, although variable in time, did not limit aphid increase *per se* however, following rain, higher humidity levels with mild temperatures promoted increased mortality by fungal pathogen, *E. neoaphidis*, in dense aphid colonies particularly during the more compact or head formation stages. The development of similar epizootics of fungal disease to high density levels of pea aphid (Gutierrez *et al.*, 1984) and to the increased humidity and favourable temperature in CA populations on Brussel's sprouts (Dunn and Kempton, 1969) have been reported.

This investigation revealed that natural enemies, parasitoids and predators, were insignificant factors in population regulation of CA under Tasmanian conditions. This finding is further supported by the fact that under field conditions the rate of increase of aphids always exceeded the influence of the key parasitoid, D. rapae. Similarly, Hughes (1963) suggested that in Canberra A.C.T. natural enemies were not effective in preventing aphids from increasing to levels limited by the food supply and that these enemies suppressed aphid numbers only after emigration when a density induced decline in the reproductive rate was already operative in lowering the aphid's rate of increase. Furthermore, results on the lack of effectiveness of D. rapae against CA in Tasmania are also consistent with the finding in South Australia by McKenzie (1977) that the parasitoid has a longer developmental time than its CA host.

Hyperparasitism is not a significant limiting factor against D. rapae in Tasmania. In contrast, Chua (1977) found that hyperparasitism was the key factor limiting the potential of D. rapae against CA in Berkshire, U.K.

The accumulation of degree-days or heat units provided a simple method to predict population performance of all 3 pest species under Tasmanian conditions. For CA, calculated heat units i.e. 223±13.5-233±14.6 approximated those counted by Hughes (1963) i.e. 250 HU's. Akinlosotu (1973) reported that CA required at least 200 HU's for development to reproducing adults.

Dispersion characteristics of both alate and apterous

CA were best described by Taylor's regression (Taylor, 1965) which clearly reflected changes in dispersion in contrast to mean crowding, Lloyd's patchiness and Green's dispersion indices. Initially, the aggregated behaviour of immigrant alates suggests that plants were positively selected. Similar aggregations in low populations of CA were reported by Trumble (1982). The present investigation further emphasizes that both alate and apterous aphids were aggregated regardless of changes in densities in time and it was because of this behaviour that CA posed a serious pest problem during the initial growth and mature stages of cabbage plants.

Adult CWB observed in early spring had emerged from overwintering pupae from the previous infestation and differences in their occurrence in any crop, were not a function of the planting dates, but the fact that CWB populations were controlled by climatic conditions, particularly temperature and photoperiod. Andaloro et al. (1982) regarded termination of diapause, immigration, presence of alternate hosts or a "combination" of these factors to be more imporatnt than the planting dates of cabbage crops.

The regular occurrence of CWB infestations during spring-summer months implies its adaptiveness to these conditions which was further enhanced by the absence of any egg mortality factor as evidenced by a consistent relationship between egg population and the larval population found 2 weeks later. In contrast, Jones and Ives (1979) reported a substantial egg mortality due to

cannibalism by 1st instar larvae. No such evidence was obtained in the present investigation and it is assumed that egg cannibalism may occur only subject to excessive oviposition and/or high larval population.

The inability of the key parasitoids, particularly A. glomeratus to significantly influence CWB populations in Tasmania is similar to their reported performance in Queensland by Hassan (1976). In contrast, Todd (1958) attributed the occasional outbreaks of CWB to the failure of control by this parasitoid in New Zealand. Multiple parasitism and searching efficiency of A. glomeratus (Ikawa and Suzuki, 1982) and its efficacy to suppress laboratory populations of CWB (Rahman, 1970) have been documented. However, despite periodic releases of this parasitoid since the late 50's by the Tasmanian State Department of Agriculture, the results indicate that it is not an effective parasitoid in this State. Similarly, granulosis virus was not an effective mortality factor despite its important role against CWB larvae in North America (Harcourt and Cass, 1968; Jaques, 1974). Although records of this virus have been made in Canberra (Wilson, 1960) and Queensland (Teakle, 1969) it has seldom been regarded as a significant source of mortality factor. Predation of immature stages of CWB by birds or ants was not a significant source of mortality in this study despite their effects as reported by Baker (1970) and Jones (1981).

Heat units required per CWB generation were 231±20 HU's which approximated the 211 $^{\circ}$D reported by Davies and

Gilbert (1985), allowed only 5 generations in Tasmania compared to 8 in N.S.W. (Peters, 1970), 6 in Canberra and 2 in Vancouver, Canada (Hughes et al., 1984). Such variations demonstrate the importance of temperature in the life strategy of this species. In Tasmania, it is concluded that population build up during spring-summer months is mainly determined by abundant food plants (cultivated and weeds) and absence or lack of effective control by natural agencies.

Although butterflies tended not to oviposit on plants infested with aphids or damaged by larvae, they did, however, not avoid those plants which already had CWB eggs. This finding agrees with Ives (1978), Traynier (1979), Root and Kareiva (1984) and Myers (1985) but contrasts with the claim of Rothschild and Schoonhoven (1977) that butterflies avoided plants with eggs due to an oviposition deterrent which limits excessive oviposition.

The tendency of young CWB larvae to feed initially on middle leaves followed by their upward movement to the head forming (folded) leaves suggests a possible need for a more sheltered habitat for protection against natural enemies (e.g. Jones and Ives, 1979) or as observed a preference for more nutritious and uncontaminated foliage as food. Plant growth stage also influenced the dispersion of CWB eggs. This is due to the fact that as plant growth progressed and foliage covered the field, egg dispersion became more aggregated. However, the larval dispersion did not follow the trends in egg dispersion which reflects the movement of particularly later instar larvae from their

original host plants. The results also indicate that Taylor's regression may reliably be used to monitor and predict dispersion trends of both egg and larval stages of CWB.

Female DM invaded cabbage crops in early spring when climatic conditions were favourable not only to moth dispersal but also establishment and subsequent increase in populations on rapidly growing host plants (both cabbage and cruciferous weeds). The results suggest that mild winters in Tasmania favoured the survival of overwintering pupae or possibly adult stages. However, Harcourt (1957) and Butts and McEwen (1981) noted that the pupal stage is incapable of surviving the colder winter conditions in Ontario, Canada.

Despite a resident DM moth population the possibility of windborn immigrant moths from mainland Australia pose continuous threats to cabbage crops in particular Brussel's sprouts in the NW Tasmania. The capacity and direction of dispersal of this moth have been related to wind pattern (e.g. French, 1966; Goodwin and Danthanarayana, 1984) involving a maximum distance upto 3200 km (see also French and White, 1960). Strong north-westerly winds are a common feature during spring-early summer between mainland and Tasmania. These evidences indicate that a large scale windborn emigration of DM moths from mainland may aggravate the pest status of this species in Tasmania. Similarly, Helm (1975) established a stronger relationship between NW wind systems and the occurrence/migration of the armyworm,

Persectania ewingii, moths from South Australia to Tasmania.

The inability of key parasitoids to suppress DM populations in Tasmania may be attributed to their higher temperature thresholds for development and slower growth rate relative to the host (e.g. Goodwin, 1976). In contrast, low densities of DM following high levels of parasitism have been reported from New Zealand (Todd, 1959) and California (Oatman and Platner, 1969). The major barrier limiting the effectiveness of these parasitoids in Tasmania is their marked asynchrony with respective host populations particularly in early spring caused by a temperature deficit.

The number of physiological heat units required to complete a generation of DM i.e. 306±9.5 HU's, were greater than those reported by Harcourt (1954) and Butts and McEwen (1981) i.e. 283 and 293±16.7 HU's, respectively. Harcourt's estimates were obtained under laboratory conditions while Butts and McEwen used a different host plant, Brussel's sprouts. The estimation of 5 complete generations in Tasmania differs from 8 in Victoria (Goodwin, 1976) 13 in Cameron Highlands in Malaysia (Hong et al., 1982) but is consistent with 5 for Ontario (Butts and McEwen, 1981). These differences emphasize the importance of heat input at different latitudes. The results also show that as for CA and CWB, Taylor's regression is the best method to monitor dispersion trends of the immature stages of this pest species.

# CHAPTER 5

# GROWTH AND PHENOLOGY OF CABBAGE AND IMPACT OF HERBIVORY

## 5.1 Growth and Phenology

### 5.1.1 Introduction

A detailed appreciation of the growth and phenology of the cabbage plant was required to monitor and describe crop performance and the effect of cultural and plant protection practices. Consequently the vegetative structure of the plants, in different growth stages was examined so that they could be conveniently categorized. In addition, growth and development of cabbage was examined with respect to heat input. Another objective of this study was to determine the influence of defoliation on the growth of cabbage and its yield parameters.

### 5.1.2 Materials and Methods

#### 5.1.2.1 Cabbage culture in growth cabinet

Five weeks old cabbage seedlings were transplanted into 20-cm plastic pots containing sand-peat mixture (50:50) with dolomite (0.5%), lime (1.0%) and Osmocote (0.1%). The potted plants (n=10) were transferred to a wooden controlled environment growth cabinet (2.8×1.2 m) in the insectary. Growing conditions in the cabinet were a constant temperature of 15$^{o}$C thermostatically maintained by a plastic coated heating cable, a relative humidity of 70±5% maintained by placing shallow plastic dishes of water underneath the wire mesh benches in the cabinet.

Temperature and humidity were measured by the probes connected to thermistors in wet and dry bulb psychrometer (Delta-T Devices Ltd., Burwell, Cambridge, England) and recorded on standard charts in Grant recorders (Grant Instruments Ltd., Cambridge, England). A photoperiod of 16 h light : 8 h dark was provided by 2 Gro-Lux 40 watt, fluorescent lamps (Sylvania Lighting Center Danvers, Massachusetts) emitting ca. 466 microeinstein $m^{-1}$ $sec^{-1}$. Light intensity was recorded by a photometer/radiometer L1-185 (Lambda Instrument Ltd.). Plants were watered every two days.

Growth data in the cabinet was collected by counting the number of leaves, leaf scars and measuring leaf area. Leaf area was obtained by the use of standard leaf charts, made by photocopying the actual leaves of all growth stage categories and determining areas with a leaf area planimeter (Paton Electronics, Melbourne, Australia). In the case of very large leaves, leaf surface area was drawn on white sheet paper (A4-A3R size) and leaf shape was cut and weighed and, from the total area of the paper involved, leaf area assessed. Calculation of physiological time (heat input) was performed by selecting 15$^{o}$C as the optimum limit for cabbage growth (Yamaguchi, 1983).

Attempts were made to determine whether any allometric relationship existed between leaf length, width, leaf vein development and total leaf area. Schematic representation of this measurement is given in Fig. 5.1.

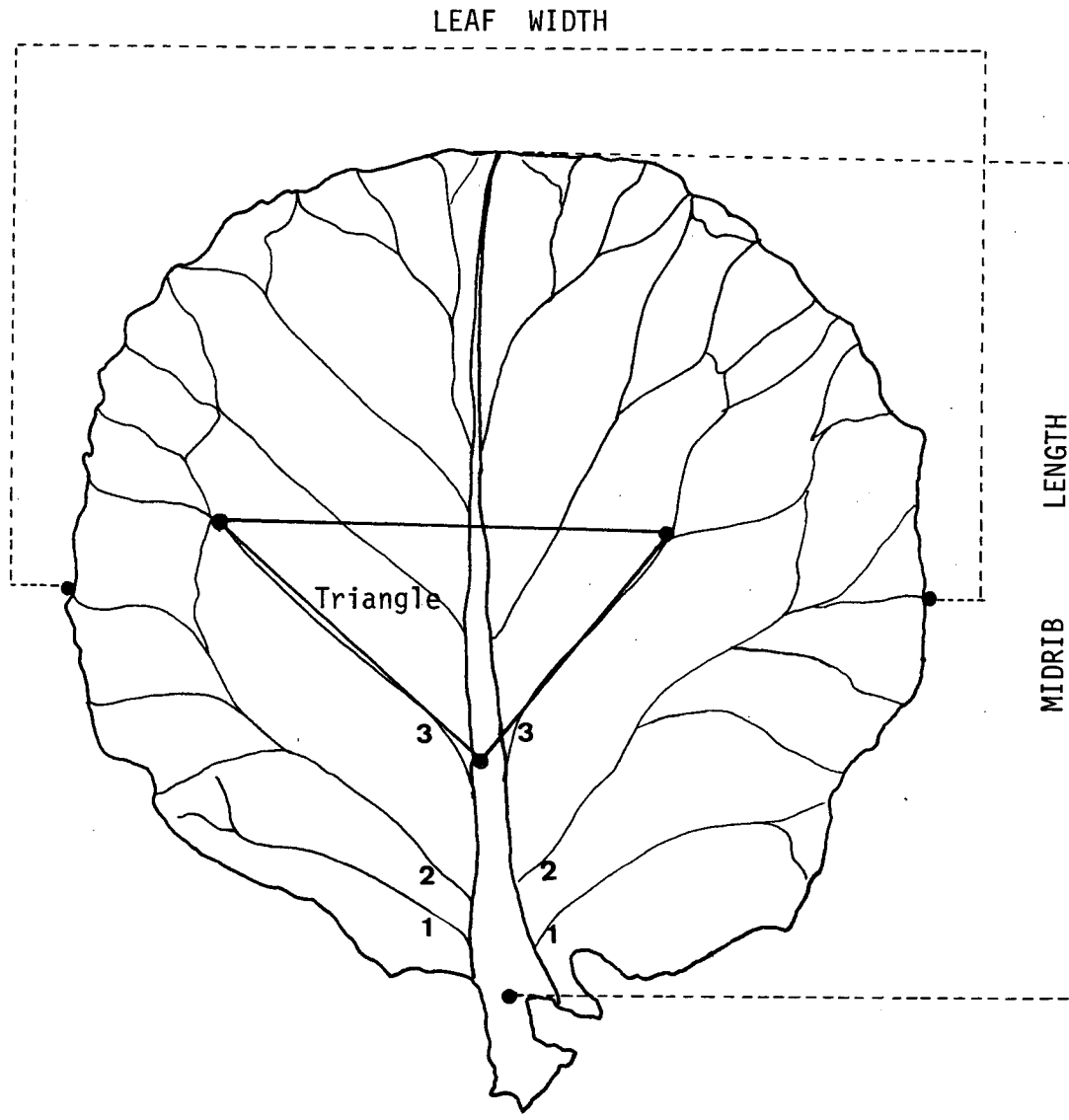



Fig. 5.1. Schematic representation of allometric relationship between the 3rd vein triangle area to the whole surface area of cabbage leaf .

5.1.2.2 Cabbage growth and phenology in field

Cabbage seedlings were transplanted to the S.J.F. College experimental plots in the method described in Chapter 3. Growth and development of cabbage was monitored in terms of the following attributes :

a. number of leaves per plant, leaves lost or number of leaf scars;
b. position of leaves on plant;
c. leaf area or leaf size and
d. stage of growth.

The average number of leaves was measured by counting the leaves on 10-30 plants, depending upon the growth stage of the crop. The area of expanded and unfolded leaves was measured in situ either by standard leaf area charts or by measuring the width and length of the leaves with a soft steel measuring tape. The leaves of the cultivar used were fairly round in shape so the formula used for the measurement of leaf area was obtained from the equation.

Leaf area = (W + L / 4)

where

W=width of leaf

L=length of leaf excluding petiole

W + L / 4 = leaf radius

This measure was adopted because of economy of time and the minimal risk of mechanical damage to the plant foliage. Leaf counts were made every week and leaf area was measured either each week during periods of rapid growth or every 14 days when plant growth was slow. Leaf

scars were marked with index paints to prevent them being re-counted on subsequent sampling occasion. Plant development was categorized in easily discernable growth stages where each stage was morphologically distinct from other stages both in age or period of development (e.g. Theunissen and Sins, 1984). Physiological time was measured from 0-25°C taken as the lower and upper developmental threshold for cabbage growth (Nieuwhof, 1969). The procedure for calculating the physiological time in terms of heat units (HU's) has been described in Chapter 4. The accumulation of heat units was commenced at transplanting and continued until maturity and growth curves relative to physiological time were produced.

Experimental plants were kept insect free by periodic application of maldison E.C. + demeton-s-methyl E.C. sprays at the rate of 1.0 + 0.5 kg/ha.

### 5.1.3 Results

#### 5.1.3.1 Cabbage growth under controlled conditions

The growth pattern of cabbage plants with respect to accumulated heat input at a constant temperature is represented in Fig. 5.2. Plant growth was linear upto the cupping stage after which leaf expansion stopped and new leaf production continued. The continuous recruitment of new leaves alongside the main stem inhibited the formation of head. Both leaf area and the number of leaves failed to provide any quantitative measure of distinct growth stages beyond this point but they did exhibit positive response to accumulated degree-days.

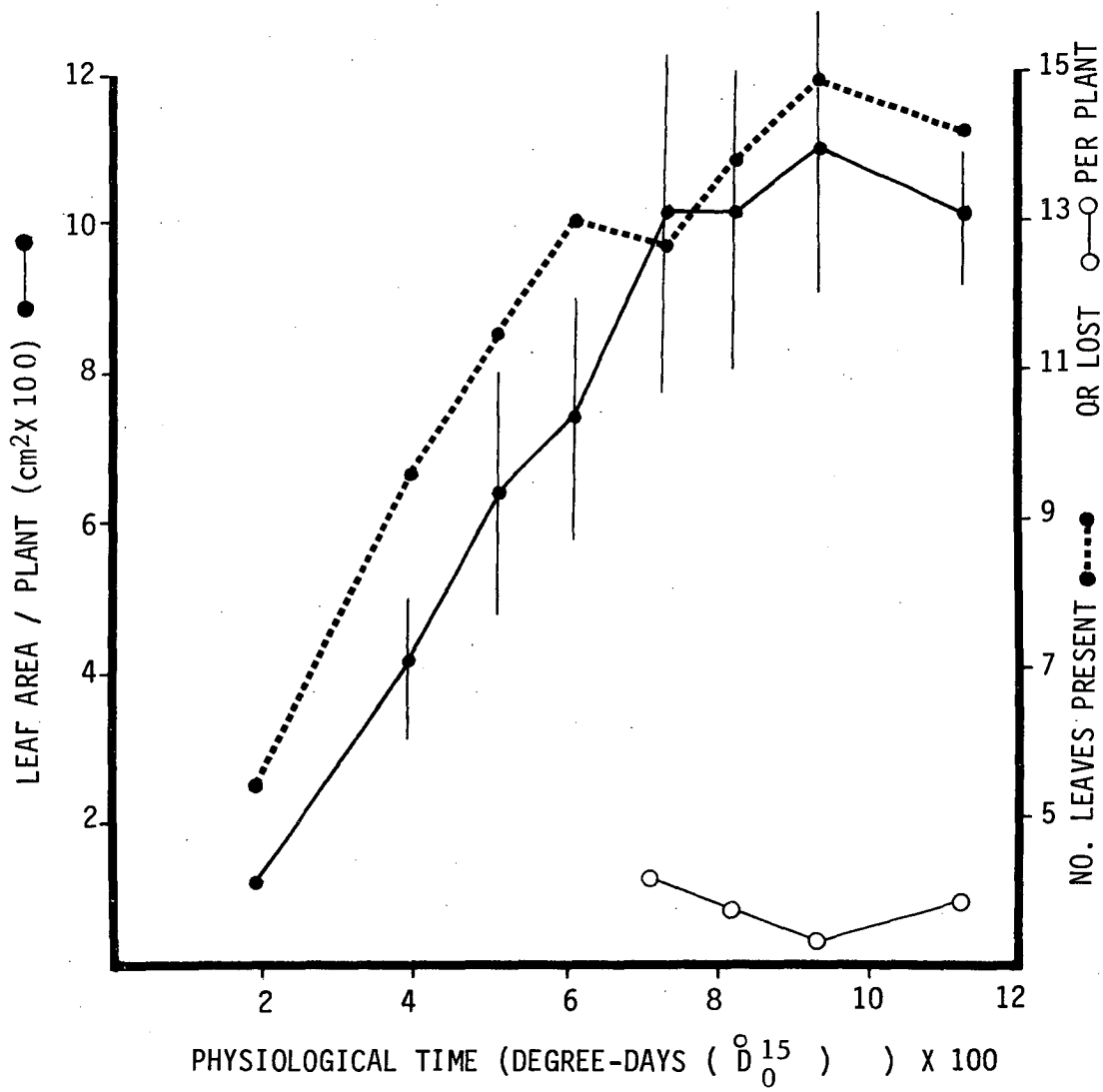



Fig. 5.2. Growth pattern of cabbage plants in experimental cabinet (28.8.82 - 10.11.82).

Vertical bars indicate S.E.

5.1.3.2 Cabbage growth under field condition

After an initial arrest in growth from the seedling to the establishment stage, cabbage plants continually produced new leaves which expanded and generally persisted throughout the life of the cabbage. Slow growth during the establishment stage was followed by rapid stem elongation and leaf growth. Six easily recognizable growth stages from seedling to maturity were identified and their individual characteristics are outlined in Table 5.1.

The number of leaves and leaf area when plotted against accumulated HU's also demonstrated the presence of 6 distinct growth stages (Figs. 5.3, 5.4).

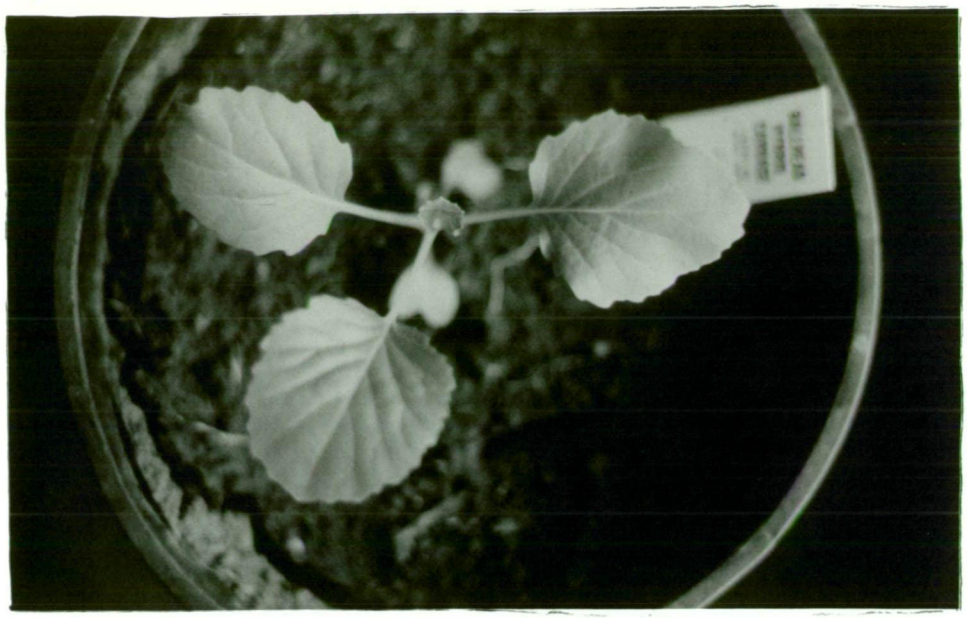
The leaves particularly the wrapper, crown and bottom leaves had a width/length ratio of ca. 1. The area of the triangle defined according to the 3rd lateral veins was positively correlated ($P<0.01$) with the total leaf area (Fig. 5.5) as was midrib length and/or width of leaf ($P<0.0005$) (Fig. 5.6)

Three pairs of leaves, on the average, were lost from each plant i.e. 1 pair at cupping stage when the first true leaves were shed and the 2nd pair between the wrapper leaf and early heading stage and the last pair fell off when the plant neared maturity (Fig. 5.4). The loss of first pair of leaves was consistent with the observations in cabinet culture.

Table 5.1 Cabbage growth, development and associated characteristics at S.J.F.College experimental plots (1982-83).

| Growth stage | Days after transplant | Growth characteristics |
|---|---|---|
| Seedling | 1-10 | True leaves exhibited little expansion and abcissed during later cupping stage. |
| Establishment | 11-20 | New leaves were formed, plant size increased with a horizontal rosette type of growth. No increase in plant height was experienced. |
| Pre cupping-cupping | 21-40 | Plant growth was exponential with rapid recruitment of new leaves. Leaves expanded and the central leaves kept upright position and turned into wrapper leaves which surrounded the subsequent bud of folded leaves. The number of unfolded leave and their total area continuously increased. |
| Post cupping | 41-54 | Central leaves were joined together and formed a frame which later supported the growth of the head. Many leaves were formed in this stage. |
| Pre heading | 55-70 | Wrapper leaves enlarged and the head consisting of loosely compacted leaves which began to develop from the inside out. The wrapper leaves later curved and covered the head. No unfolded leaves were produced from this stage onward. |
| Heading | 71-101 | Head appeared and increased in size until harvest obviously this stage contained very rapid biomass accumulation. No new leaves were produced and the growth was centered on the meristematic tissues inside the head. |

Fig. 5.3. Successive growth stages of the cabbage plant.



1. Seedling stage

2. Post seedling stage

3. Early cupping stage

4. Cupping stage

5. Post cupping stage

6. Pre heading or head initiation stage

7. Heading or harvest stage

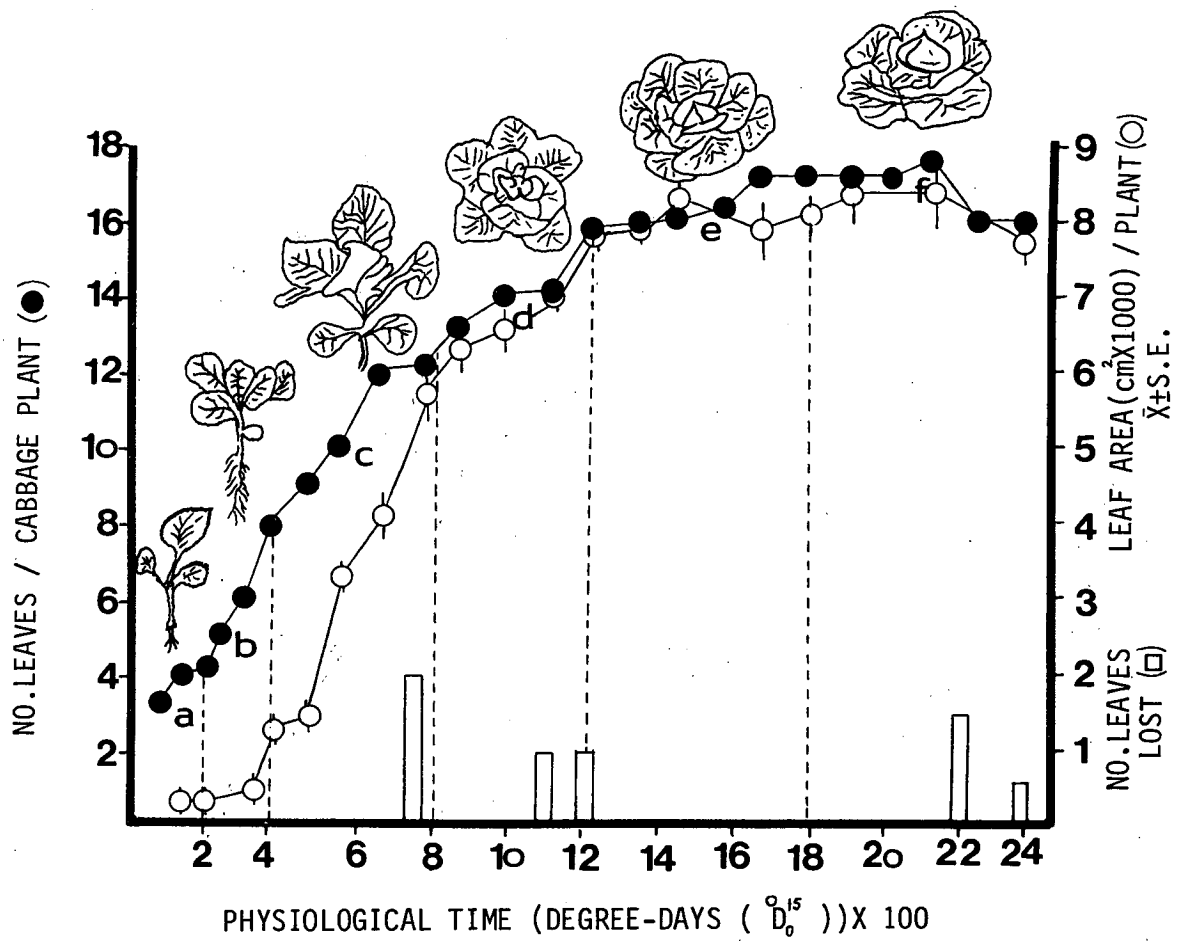



Fig. 5.4. Growth and phenology of cabbage at S.J.F. College plots (1982-83).

a : Seedling stage
b : Post seedling/establishment stage
c : Cupping stage
d : Post cupping or wrapper leaf stage
e : Pre heading or head initiation stage
f : Heading or harvest stage

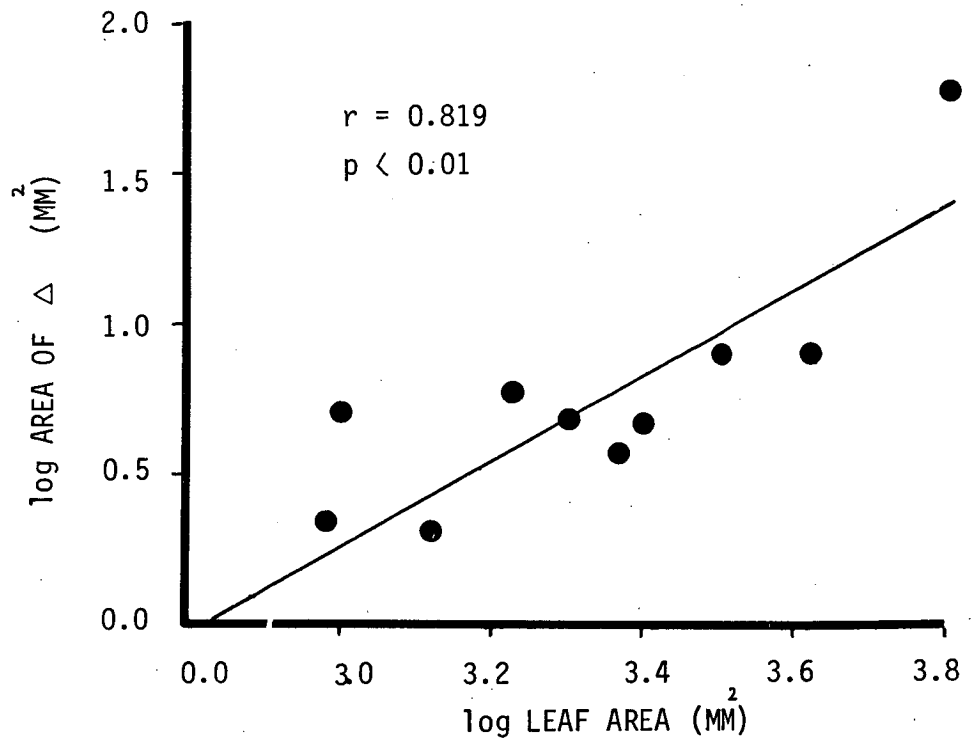



Fig. 5.5. Relationship between total leaf area and the area of 3rd vein △ on cabbage leaf.

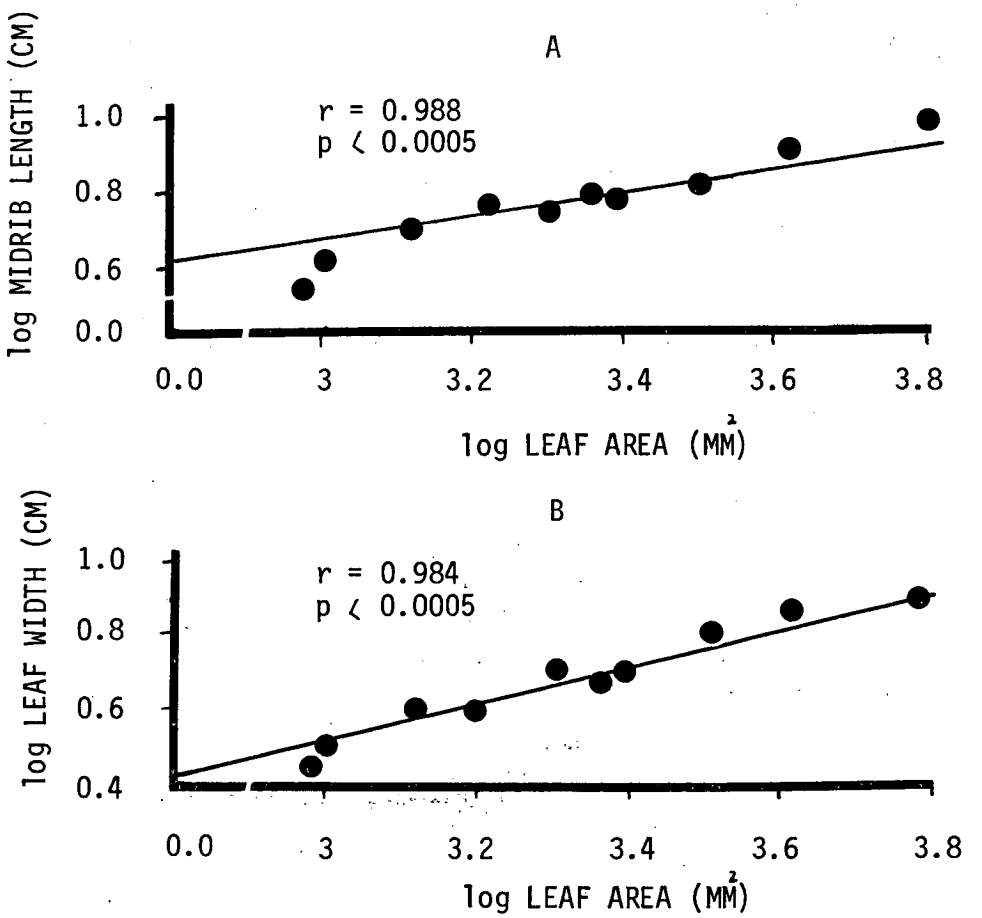



Fig. 5.6. Relationship between total area and midrib length (A) and width (B) of cabbage leaf.

5.1.4 Discussion

Plant growth under controlled conditions followed normal vegetative growth but failed to enter the heading stage continuing to produce new leaves. This aberral behaviour is attributed to lack of chilling or vernalization as the plants required exposure to low temperature (7 °C) to induce bolting (Yamaguchi, 1983). The designation of the cabbage plants at different time in their phenology into readily identifiable morphological stages permitted simple and rapid monitoring of crop response to both biotic and abiotic processes. The classification of cabbage life cycle into different growth stages has been utilized by various workers (e.g. Harcourt, 1970; Strandberg, 1979; Samson and Geier, 1983; Theunissen and Sins, 1984) depending upon the purpose or their experimental objectives. Few authors have attempted to categorize cabbage life cycle with respect to insect infestations. Growth stages for this purpose were only described as pre cupping and cupping (Chalfant et al., 1979), pre heading and heading (Shelton et al., 1982), establishment, pre heading, heading and harvest (Harcourt, 1970) and weeks after transplanting (Theunissen, 1984). These classifications of growth of cabbage were too general to be utilized in this study and the use of 6 growth stages in this study provided continuous description of pest-plant-damage relationships. Nieuwhof (1969) described cabbage growth and development from a botanical viewpoint and emphasized bud formation and flowering. However, Samson (1981) utilized the cumulative increments of temperature (degree-days) as well as days after transplant. He considered 5 growth stages. Harcourt

(1970) considered four growth stages (periods) based upon calender dates. Calender time is a poor index of growth, for it omits the annual variations in climate.

This study showed that cabbage growth and development could be described and predicted by utilizing information on distinct morphological stages and the input of heat, degree-days, in a particular cropping system.

## 5.2 Impact of Herbivory on Cabbage Growth

### 5.2.1 Introduction

Herbivory may not always result in the reduction of yield as compensation may take place by which the plant decreases the effect of injury or damage (Bardner and Fletcher, 1974; Harris, 1974). Leaf area is one of the major determinants of the yield of a plant which varies either by new growth, abscision, damage or injury. This study was designed to :

(i) determine the effect of defoliation of cabbage using the garden snail, Helix aspersa O.F. Muller (Helicidae : Gastropoda), as a general herbivore and

(ii) evaluate the response of cabbage to two defoliations at 2 different growth stages namely cupping and pre heading. Snails were used because they:

a) do cause damage to cabbage,

b) were readily available and

c) caused defoliation which was easily quantified.

5.2.2 Materials and Methods

Individual cabbage seedlings (3-weeks old) were transplanted into 20-cm plastic pots. They were regularly watered, and supplied with nutrients. At the time of defoliation an individual pot was set in a rearing cage (0.75x0.75m) covered with nylon mesh. The following defoliation programme was performed.

(i) Defoliation I at cupping leaf stage ($D_1$);

(ii) Defoliation II at pre heading stage ($D_2$);

(iii) Defoliations I & II at cupping and pre heading stage ($D_{1+2}$);

(iv) Control (no defoliation ($D_0$)).

5.2.2.1 Defoliation I

At the cupping stage 6 snails were placed on each plant in each cage. Snails were frequently put back on the cupping leaves to maximize feeding damage and the plants were exposed to their feeding for 2-days. Subsequently plants were removed from the cages and grown under glass house conditions to maturity. Plants were kept insect free by repeated sprays of pyrethrum. Number of leaves per plant and leaf area were continuously assessed by the method outlined earlier.

5.2.2.2 Defoliation II

This infestation was initiated when the plants entered the pre heading or wrapper leaf stage (ca.55 days old). Each plant was exposed to 10 snails for 2 days. Both

undefoliated and defoliated plants at cupping stage were subjected to feeding by snails. Number of leaves and leaf area were recorded *in situ* until maturity of cabbage plants. Damaged areas were calculated by drawing the size of the holes or parts of the leaf fed upon by weight/area tracing method.

### 5.2.2.3 Harvesting

At maturity the plants were carefully removed and soil washed from roots. Fresh weights of total foliage, head and roots were taken immediately after harvest. Dry weights of foliage and roots were obtained after oven drying (70-75 °C) for 7 days. Stem diameters were measured with callipers. The impact of defoliation was analyzed using L.S.D. comparisons.

## 5.2.3 Results

Pattern of damage by snails differed with stages of defoliation. Small upper leaves were attacked severly while larger leaves had holes of variable sizes. Older leaves were less attacked and were most often "grazed" on both upper and lower surfaces.

The effect of time and frequency of defoliation by snails is presented in Fig. 5.7. There was a significant decrease ($P=0.05$) in the leaf area of defoliated plants immediately after the first defoliation at the cupping stage and changes in leaf area remained significantly different from undefoliated plants. At the pre heading stage the defoliation of previously undefoliated plants

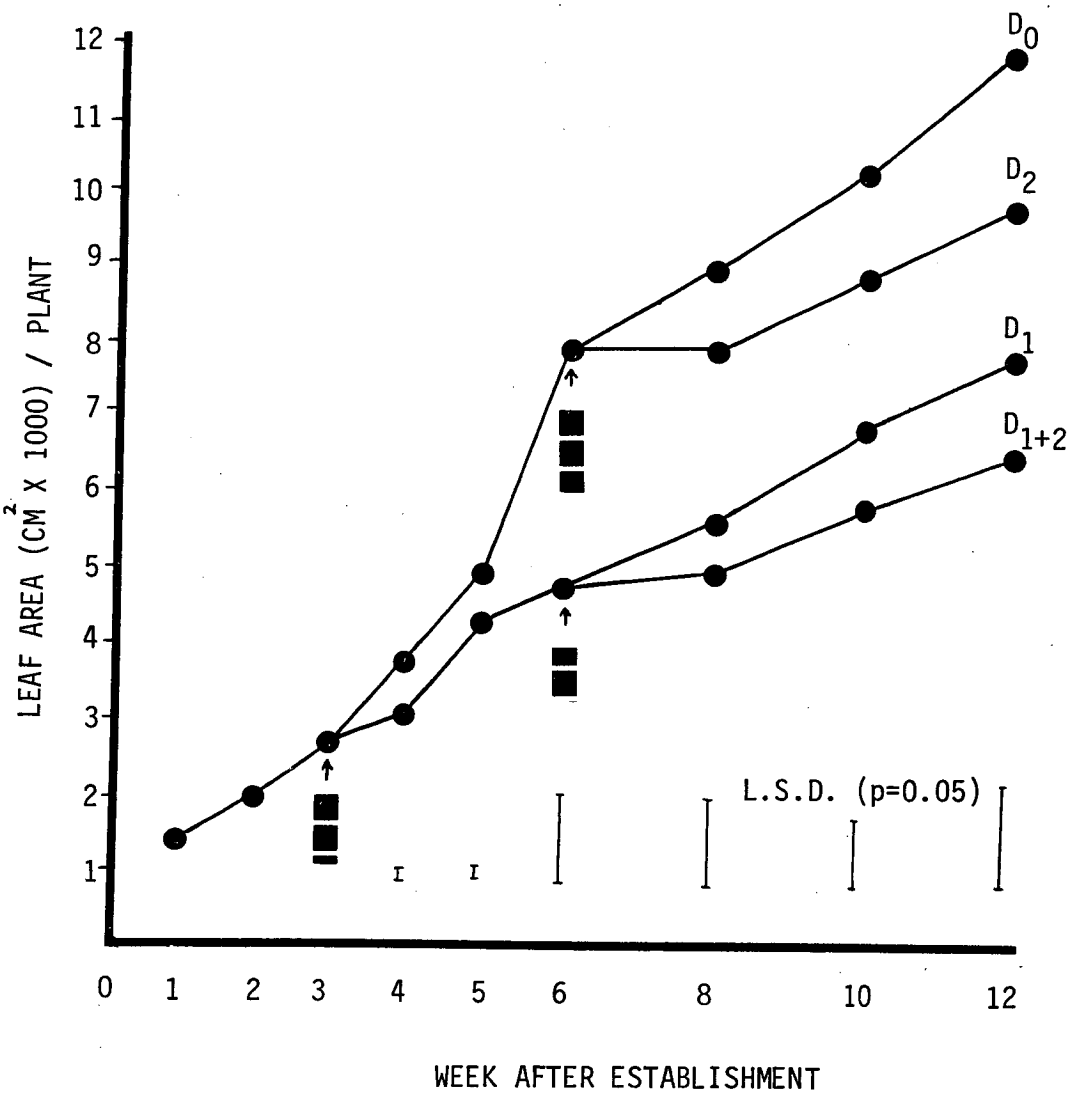



Fig. 5.7. Effect of snail infestation(s)/defoliation(s) on the growth of cabbage plants. Arrow indicates the time of infestation.

$D_0$ Control (no defoliation);

$D_1$ Defoliation at cupping stage;

$D_2$ Defoliation at pre heading/wrapper leaf stage;

$D_{1+2}$ Defoliation at cupping and pre heading stages.

■ Leaf area defoliated

showed a significant reduction in leaf area only on the last two samplings. Defoliation of previously defoliated plants (i.e. $D_{I+2}$ ) did not cause a significant reduction in subsequent leaf area production compared to those plants which were defoliated at the cupping stage ($D_1$ ). Defoliation at the cupping stage caused a significant loss in subsequent leaf area production. However, defoliation at the pre heading stage was less disruptive to the leaf area economy than at the cupping stage. Cabbage plants exhibited greater growth in leaf area following defoliation at cupping stage than at pre heading stage.

Positive and significant correlations ($P<0.01$, $P<0.005$) were obtained between the leaf area production and the yield components (e.g. total fresh weight, head weight, etc.) in all treatments regardless of the timing and levels of defoliation (Fig. 5.8). Likewise, significant correlations existed between the leaf area produced and stem diameter or root weight (Fig. 5.9). Stem diameter was strongly correlated ($P<0.0005$) with root weight (Fig. 5.10).

Significant reductions in total fresh weight and head weight occured when plants were subjected to a single defoliation at cupping stage or multiple defoliation at both the cupping and pre heading stages. However, single defoliation at the pre heading stage did not cause any significant decline in these attributes (Fig. 5.11). An interesting feature of the effect of multiple defoliations was the significant reductions in the root weight and stem diameter.

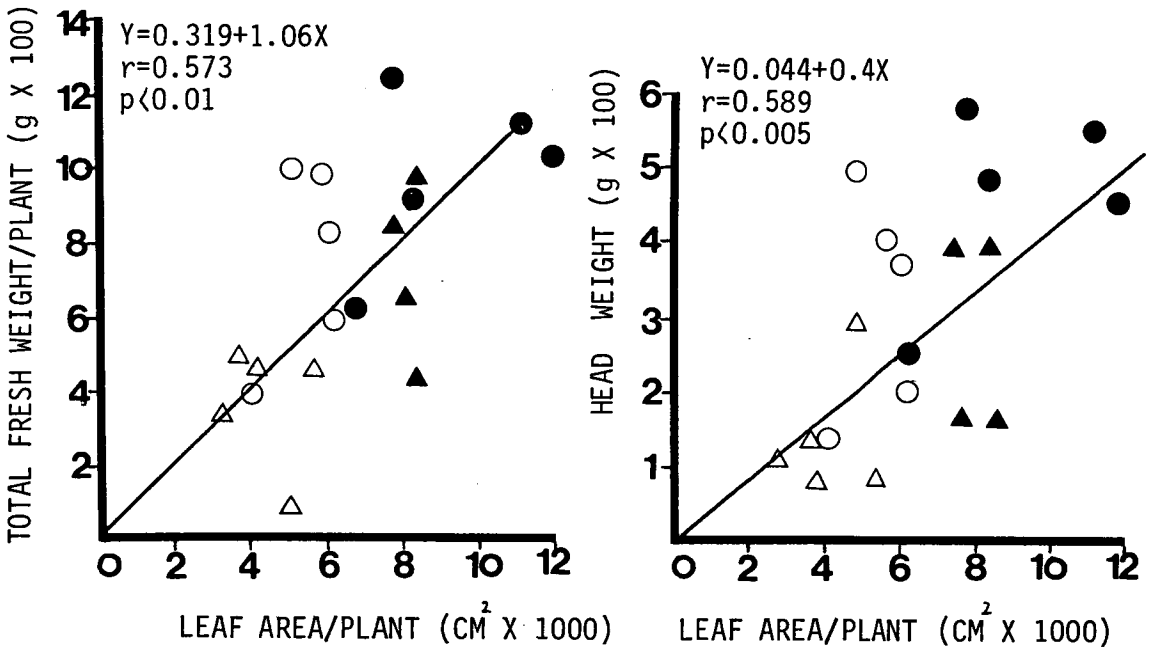



Fig. 5.8. The relationships between leaf area production and yield (fresh whole weight and head weight of cabbage plants.

● Undefoliated plant
○ Defoliated at cupping stage
△ Defoliated at cupping and pre heading stages
▲ Defoliated at pre heading stage

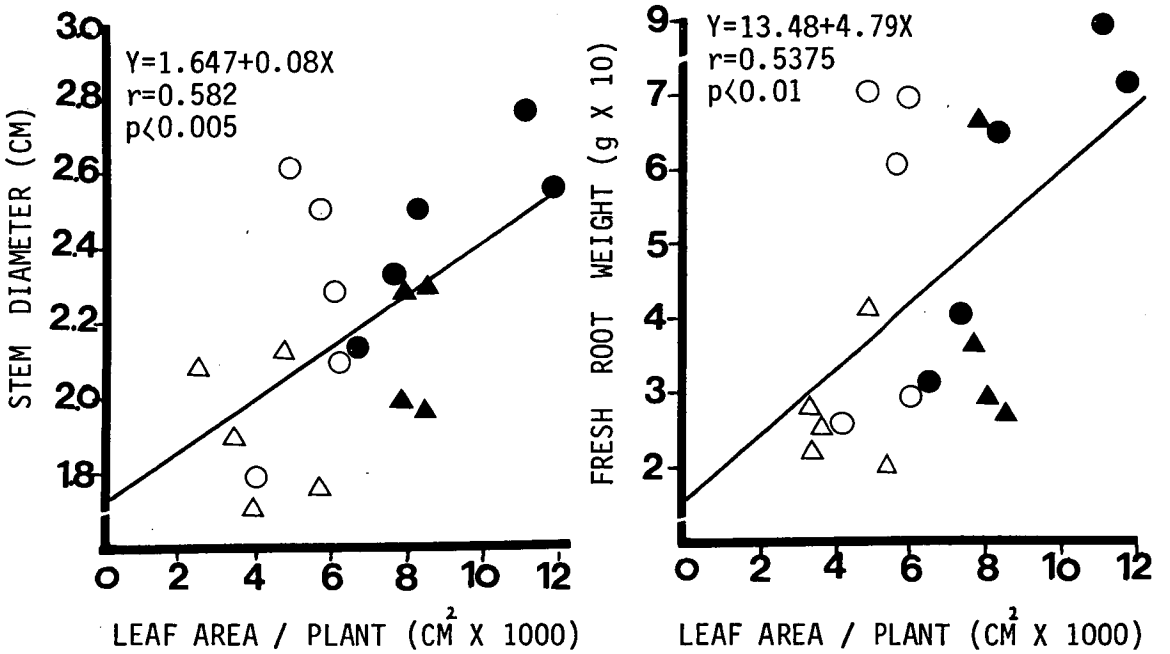



Fig. 5.9. The relationship between leaf area production and stem diameter and root weight of cabbage plants.Treatment symbols similar to those in Fig.5.8.

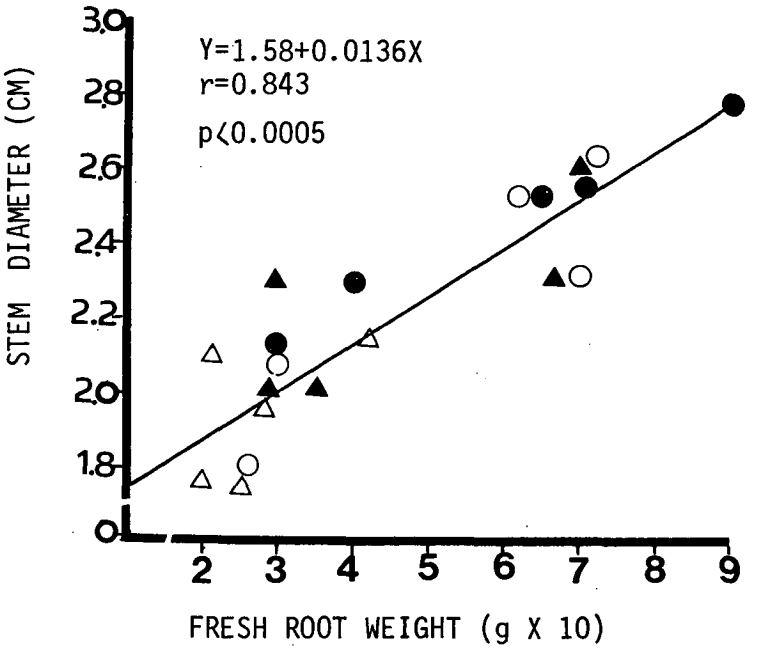



Fig. 5.10. The relationship between root weight and stem diameter of cabbage plants at harvest stage.

- ● Undefoliated plants ;
- ○ Defoliated at cupping stage ;
- ▲ Defoliated at pre heading stage ;
- △ Defoliated at cupping and pre heading stages.

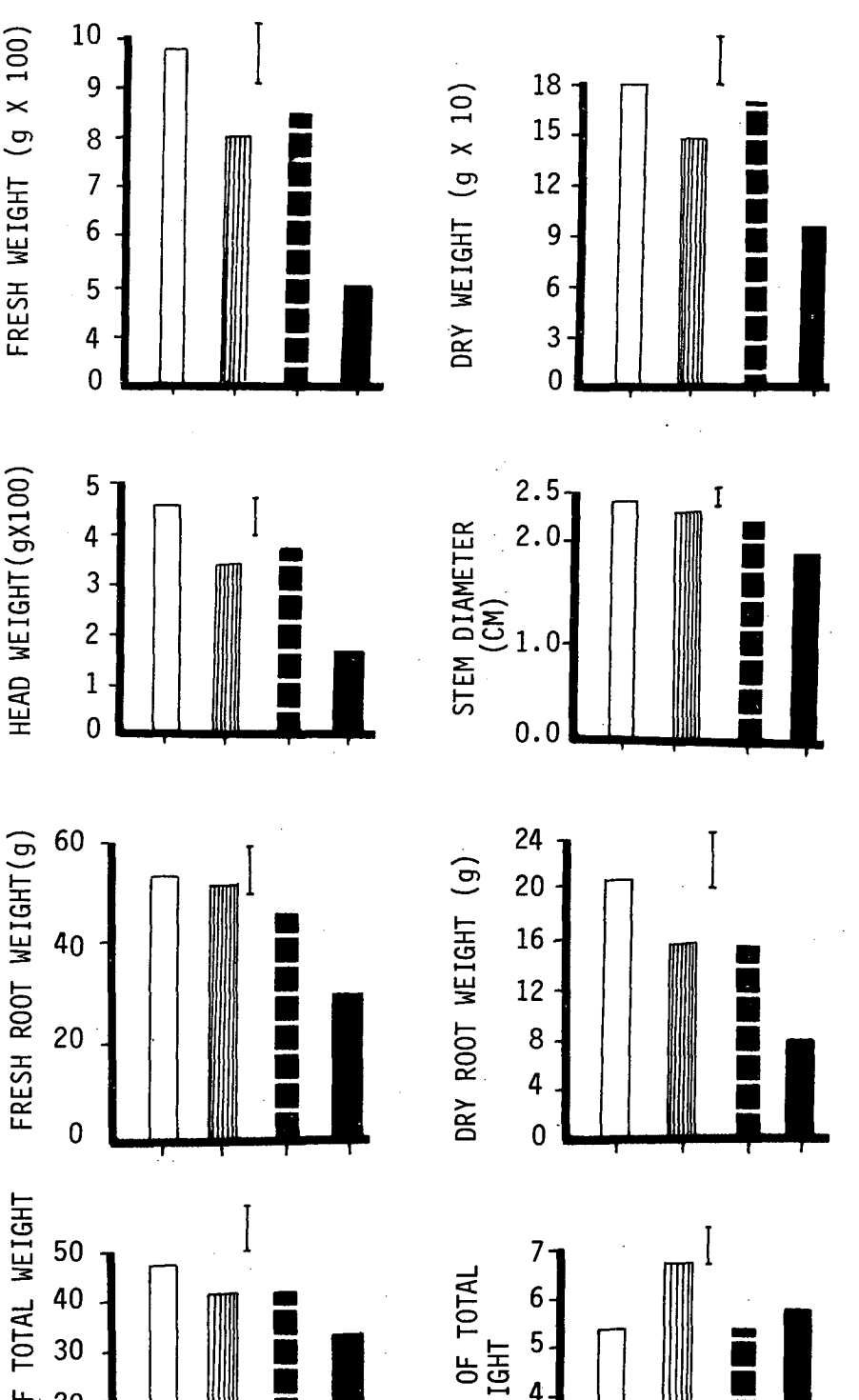



Fig. 5.11. Effect of snail infestation / defoliation on the growth characteristics of cabbage plant. Vertical bars indicate L.S.D.(P=0.05).

Undefoliated plant

Defoliated at cupping stage

Defoliated at pre heading stage

Defoliated at cupping and pre heading stages

Single defoliation at the cupping or pre heading stage did not significantly decrease the head weight relative to the total fresh weight. In contrast, multiple defoliation caused a significant decline of this proportion. Root weight relative to total fresh weight in plants which experienced single defoliation at cupping stage was significantly higher than other treatments and control.

### 5.2.4 Discussion

The pattern of cabbage plant growth following defoliation was easily discernable from responses in leaf area production. The fresh weight, head weight, root weight and stem diameter responded positively to leaf area production and the results support the importance of total leaf area on the productivity of cabbage plant. Watson (1956) also considered that for many crops the yield was directly proportional to the leaf area. Following establishment, cabbage plant exhibited an exponential trend in leaf growth and it was in this stage when the defoliation caused maximum loss in the components of yield. This loss indicates that the demand of respiration and new growth exceeded the supply of current photosynthesis and amount of available metabolites which caused reduction in leaf growth. Dunning and Winder (1972) reported similar responses in sugarbeet.

The results demonstrate that leaf growth continued at decreased rate after defoliation at cupping stage and possibly altered or curtailed the normal partitioning of photosynthates between foliage, stem and roots (e.g. Hare,

1980). However, losses in this stage were not compensated by achieving a similar area as in undefoliated plants (see also Jackson, 1980). Samson and Geier (1983) attributed the losses in yield of cabbage to the induced destruction of the apical meristem. Likewise, Baker (1984) considered that the destruction of the apical bud of cabbage by DM larvae caused significant loss in yield, however, Taylor and Bardner (1968) noticed that the photosynthetic activity of turnip plants defoliated by DM was increased in the remaining leaves which grew larger than comparable leaves in undefoliated plants. Bardner and Fletcher (1974) and Harris (1974) explained the plant yield increase after insect damage.

Following defoliation at pre heading stage the plants continued their normal growth indicating that defoliation at this stage did not affect the translocation of assimilates from adjacent undefoliated leaves and in turn did not affect the yield parameters. Salter (1959) demonstrated that the curd size of cauliflower was directly proportional to leaf area at pre heading stage. However, Shelton et al. (1982) considered that larval feeding of cabbage before head formation did not cause any loss in the marketability of cabbage. Samson and Geier (1983) observed an increase in tolerance to infestation of CWB larvae during later stages of plant growth. The cumulative effect of multiple defoliation was generally greater than the sum of losses imposed singly. This effect, although very complex to interpret, was possibly due to the multiple reduction in the supply of assimilates

to the damaged leaves (areas) (see also Davidson and Milthorpe, 1965). However, the existence of other inherent processes (e.g. Youngner, 1972) can not be ruled out and thus interpretation may have been oversimplified. Multiple defoliations also had a pronounced effect on the average head weight, root weight (fresh and dry) and stem diameter. These parameters were significantly decreased and resulted in poor yield. Similarly, reduction in root growth of grasses following defoliation has been associated with the reduction in the amount of photosynthetically active tissues (leaf area) by Troughton (1957).

An examination of the cabbage growth pattern revealed that growth rate tended to slow before the plant entered into new and morphologically distinct growth stage. This response is attributed to the already timed harmonal activity within the plant.

This study demonstrated the need for protection of leaf area particularly at cupping stage to obtain optimum productivity of cabbage plant.

# CHAPTER 6

# EVALUATION OF PEST CONTROL PRACTICES OF COMMERCIAL CABBAGE GROWERS

## 6.1 Introduction

At the commencement of this investigation no information on the nature and frequency of conventional insecticide applications in commercially grown cabbage crops in Tasmania was available. This aspect of the study investigated how the crop protection measures and in particular insecticidal control of 3 major insect pests of cabbage were adopted in commercial farms. Grower's insecticidal use, costs, resultant losses due to insects and the effectiveness of control measures were determined. The study also attempted to collect information on the seasonal fluctuations of insect pests and their natural enemies occuring on successive cabbage crops. The information collected provided a base line set of data to define the real problem as well as the effectiveness of the existing pest control strategies.

## 6.2 Materials and Methods

### 6.2.1 Selection of commercial farms

Two commercial properties located at Campania and Kingston were selected for a regular survey of crop protection practices and their effectiveness. Timing of survey was arranged in a way which allowed :

(a) collection of insect pest population data before and after each spray application and

(b) on-farm consultation with the grower or his manager to obtain information on cultural practices, pesticides used, their frequency and costs.

Physical characteristics of each site has been outlined in Chapter 2.

### 6.2.2 Monitoring of insect pest population

Insect pest populations were monitored by direct *in situ* counts on 40-50 randomly selected plants in inner rows in a random walk along the length of the fields. Each plant was examined carefully and all stages of each insect pest or their natural enemies recorded. Sampling was continued from the seedling to maturity or harvest stage by which time the next crop was planted out. In this way 7 successive crops at Campania (Oct.82-Feb.85) and 6 at Kingston (Dec.82-Feb.85) were surveyed.

Trapping methods such as sticky traps, yellow modified Moericke traps, sweep-net trap (Dec.82-Jan.84) pitfall traps and pheromone traps (Aug.83-Jan.84) were employed to monitor the abundance of active stages of insect pests and their natural enemies. The methodology of these trapping devices has been described in Chapter 4.

To determine the natural enemies associated with each insect pest species, the immature stages of individual pest species (nymphs and aphid mummies for CA and larvae or pupae for CWB and DM) were either isolated from the

plant or collected with small peices of cabbage leaves.

Leaves and insects were taken to laboratory/insectary for rearing and parasitoid emergence. Parasitism was calculated as described in Chapter 4. Both commercial fields were surveyed on the same day with few exceptions when no new crop was planted out after the harvest of previous crop. Survey interval varied from 10-30 days depending upon the season.

### 6.2.3 Effectiveness of insecticidal sprays

The efficacy of each insecticidal spray was determined by systematic counts of insect pests both before and after the spray. Insecticidal data comprising the toxicant used, dosage, and on some occasions number of sprays between two survey dates were obtained from the cooperative growers. The performance of those sprays which had prior infestation of insects pests was evaluated in terms of percent reduction as used by Eckenrode *et al*. (1981), i.e.

$$\% \text{ reduction for aphids} = \frac{\% \text{ plants infested (pre treatment - post treatment)}}{\% \text{ plants infested pre treatment}} \times 100$$

$$\%\text{reduction for CWB/DM larvae} = \frac{\text{No. of larvae (pre treatment - post treatment)}}{\text{No. of larvae pre treatment}} \times 100$$

### 6.2.4 Grower's attitude to pest control operations

Through personal interviews of the growers, relevant information on acreage, variety, date of planting/harvest, pesticide formulation and dosage, date of spray and area

sprayed, grower's objectives, their perception of insect damage and decision making for control measures, fixed and variable costs involved in cabbage production and varietal preference were obtained and comparisons were made between the two commercial growers. Occasionally farms were visited on the spray day and information on the methodology of spray was collected. The market price of toxicants was obtained from local pesticide dealers.

### 6.2.5 Assessment of insect damage

Crops at maturity or harvest were examined to evaluate the insect damage based upon a rating scale of 1-6 (Greene et al., 1969) where,

1 = no damage i.e. no feeding hole or aphid contamination ;
2 = slight outer leaf damage or outer leaves with 1-5 aphids per leaf;
3 = moderate outer leaf damage or outer leaves with 6-25 aphids per leaf;
4 = slight damage to wrapper leaves or wrapper leaves with 1-25 aphids per leaf;
5 = moderate damage to wrapper leaves or wrapper leaves with severe aphid infestation;
6 = slight to severe damage to the head or head with slight to severe aphid infestation.

Heads rated $\leqslant$ 3 on rating scale were recorded as marketable (Chalfant, 1979). This system was also based on

accepted market standards as informed by the growers.

## 6.3 Results

### 6.3.1 The extent and pattern of insecticide usage

The seasonal population abundance of the damaging stages of each of the major pest species under each spray at Campania and Kingston is presented in Figs. 6.1, 6.2, 6.3. At Campania, generally the crops received more sprays during the initial and mature stages of the crop growth. However, crops were continuously colonized by immigrant alate aphids causing persistent contamination of cabbage plants. In crop VI, due to the low number of insecticidal sprays in the mid season, aphid populations were established at head formation stage and fortnightly sprays at crop maturity could not adequately suppress the aphid infestation. The resultant crop was not harvested and was grazed by sheep stock. In all the crops lepidopterous pests (CWB and DM) were effectively controlled by the sprays.

At Kingston, aphid populations were generally too low to warrant any use of aphicide except in crop II and V when one spray of thiometon and demeton-s-methyl was applied respectively. However insecticidal schedules generally proved effective against lepidopterous pests.

At Campania the grower applied 75% of total sprays as combination sprays (2-toxicant sprays) whereas at Kingston only 6% of the sprays were applied in combination (Fig. 6.3). At Campania the grower used either thiometon or

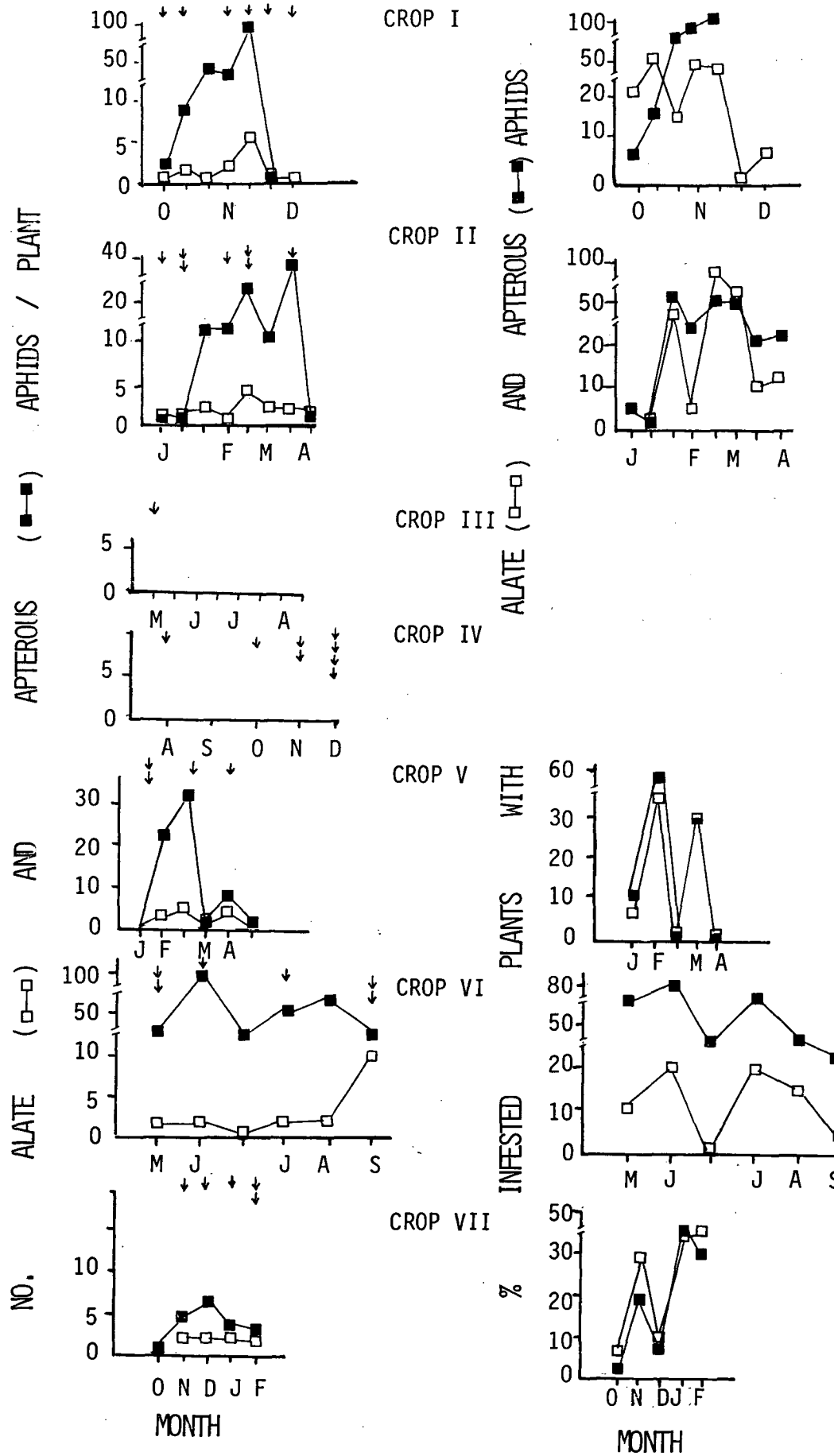



Fig. 6.1. Cabbage aphid infestations and insecticidal applications at commercial cabbage fields at Campania (1982-85). Arrow indicates insecticidal spray.

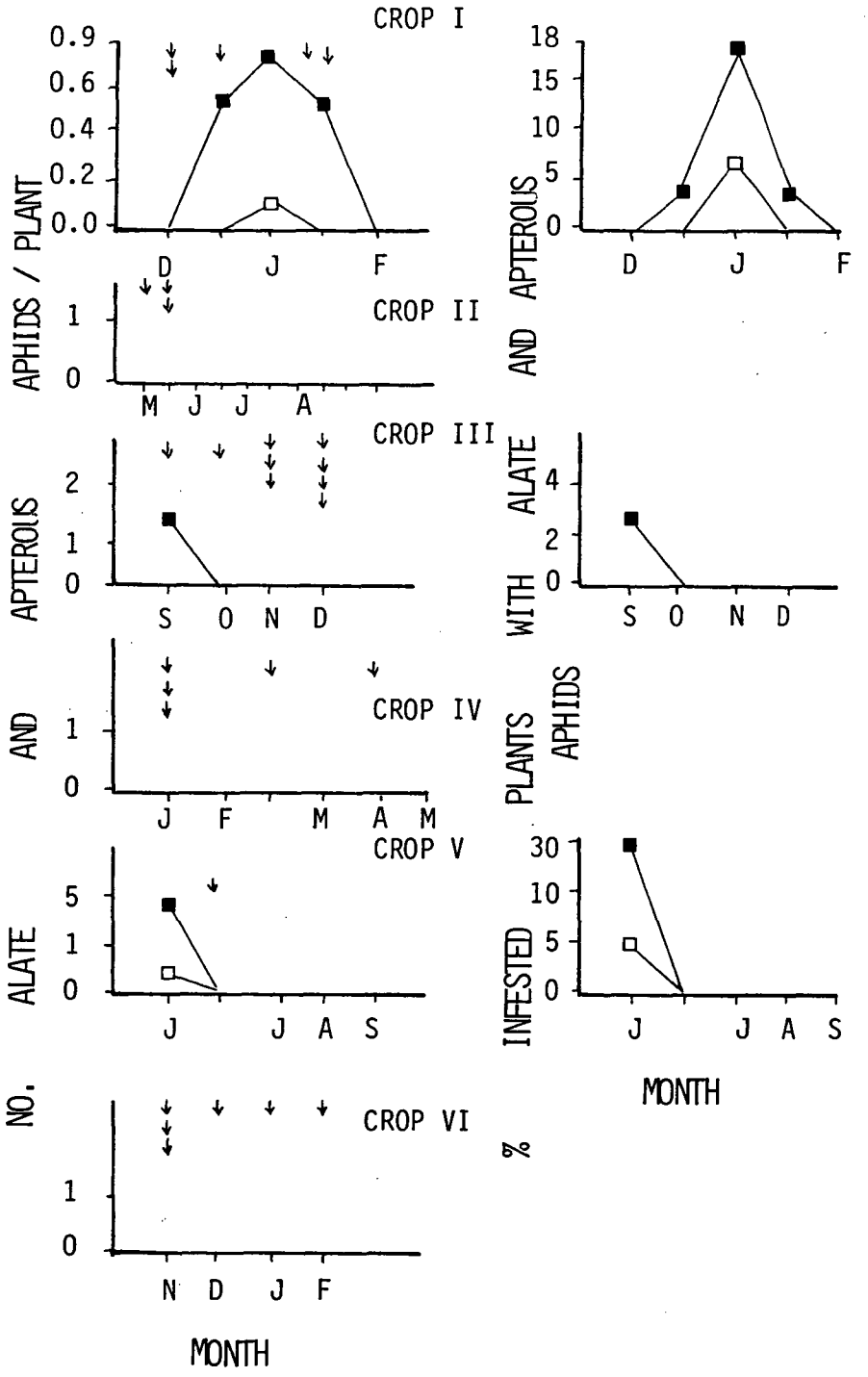



Fig. 6.2. Cabbage aphid infestations and insecticidal applications at commercial cabbage fields at Kingston (1982-85). Arrow indicates insecticidal spray.

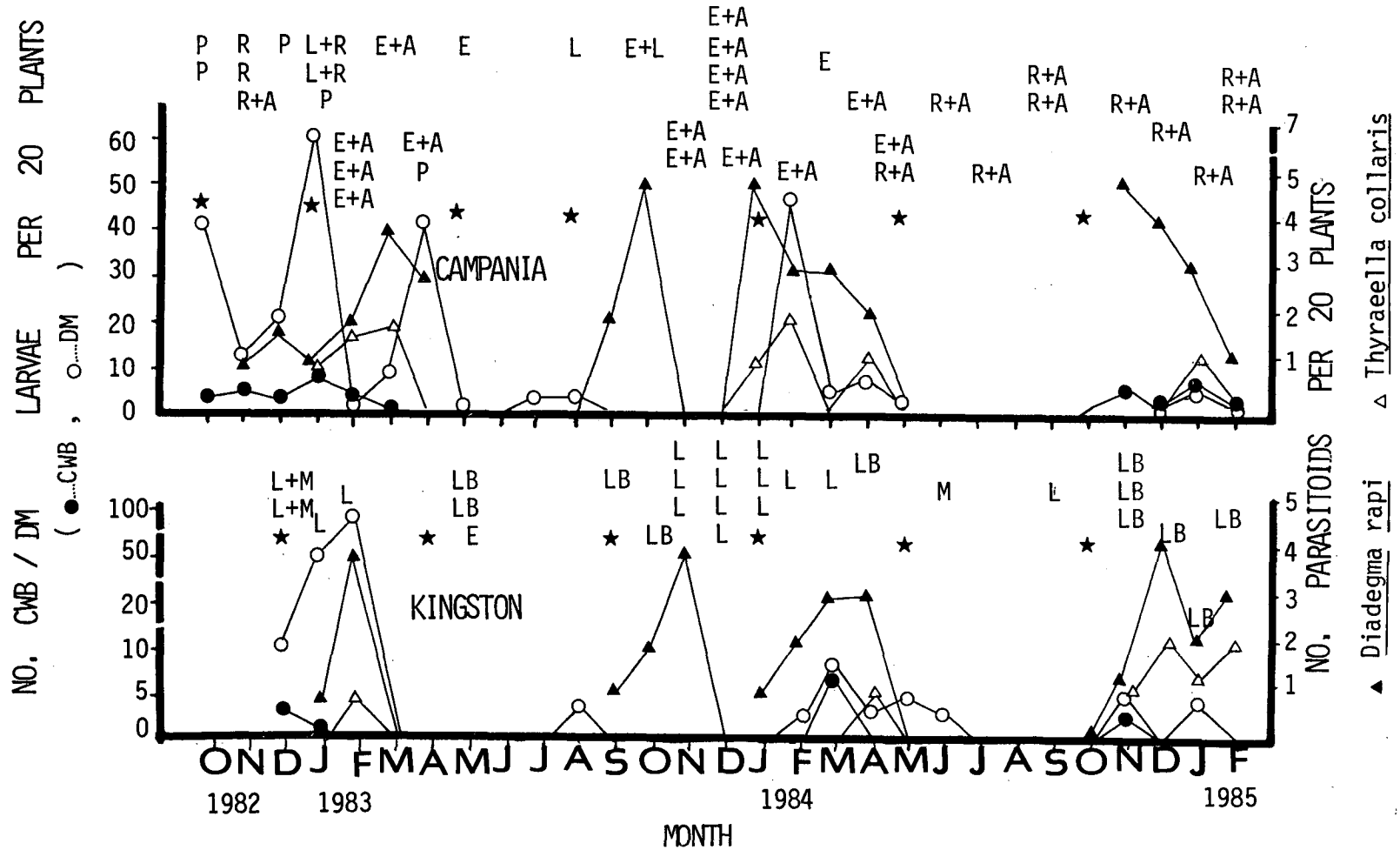



Fig. 6.3. Populations of cabbage white butterfly (CWB) and diamondback moth (DM) larvae, their parasitoids and schedules of insecticidal sprays in commercial cabbage fields at Campania and Kingston. Number of insecticidal application is given by the number of abbreviation singly or in combination. Toxicants abbreviated as A...permethrin; E...thiometon; L...methomyl; LB...chlorpyriphos; M...demeton-s-methyl; P...mevinphos; R...dimethoate. Star indicates the planting of new cabbage crop.

dimethoate against aphids in combination with permethrin which was intended to control lepidopterous pests. In contrast, the grower at Kingston used either methomyl or chlorpyriphos for total pest control. Seasonally, there was no consistency of number of sprays applied by two growers. Moreover, variable number of sprays were applied in different crops by each grower.

### 6.3.2 Reduction of cabbage aphid and lepidopterous pests

The average effectiveness (% pest reduction) for insecticides used against CA and/or lepidopterous pests is depicted in Tables 6.1, 6.2. At Campania most of the insecticidal combinations provided marked reduction of lepidopterous pests but dimethoate plus methomyl and thiometon plus permethrin reduced both aphids and lepidopterous larvae more effectively than other insecticides applied singly or in combination. However, dimethoate plus permethrin and mevinphos did not adequately suppress aphid populations.

At Kingston chlorpyriphos sprays provided a satisfactory control of both CWB and DM larvae. Demeton-s-methyl was markedly effective against CA and interestingly the DM larval population was also reduced. The reduction in DM larvae may have occured due to some other factors and the mortality of larvae due to the systemic action of demeton-s-methyl could be misleading. Methomyl spray was very effective against CWB larvae but failed to adequately reduce both aphid and DM larval

Table 6.1 Effectiveness of insecticides on cabbage pests in commercial fields of cabbage in Campania (1982-85).

| Insecticide | Rate of application (kg.AI/ha) | Mean % reduction a CA | b CWB | b DM |
|---|---|---|---|---|
| Dimethoate + permethrin | 0.60+0.15 | 53.9(5) [c] | ? | ? |
| Dimethoate + methomyl | 0.60+0.45 | 100(2) | 67.5(2) | 100(2) |
| Methomyl | 0.50 | ? | ? | 100(1) |
| Mevinphos | 0.50 | 65(2) | 100(1) | 93(1) |
| Thiometon + permethrin | 0.60+0.10 | 86.6(3) | 100(2) | 96.6(3) |

a Mean % reduction in plants infested.
b Mean % reduction in larval population.
c Number in parenthesis indicates the total number of observations.
? Insect pests were not present prior to spraying.

Table 6.2 Effectiveness of insecticides on cabbage insect pests in commercial cabbage fields at Kingston (1982-85).

| Insecticide | Rate of application (kg AI/ha) | Mean % reduction a CA | b CWB | b DM |
|---|---|---|---|---|
| Chlorpyriphos | 0.50 | ? | 98.7(8) [c] | 91.6(7) |
| Demeton-s-methyl | 0.75 | 100(1) | 100(1) | 100(1) |
| Methomyl | 0.50 | 88.5(2) | 100(1) | 65.6(2) |

a Mean % reduction in plants infested.
b Mean % reduction in larval population.
c Number in parentheses indicates the total number of observation.
? Insect pests were not present prior to spraying.

populations.

The trends in DM larval populations at Campania and Kingston suggested that after most of the sprays a small but persistent residual population of the larvae survived from one application to the next. A similar situation may also have occured with aphid population at Campania.

### 6.3.3 Abundance of parasitoids and predators

Numbers of the parasitoids of DM, D. rapi and T. collaris, recorded on the cabbage plants during sampling are presented in Fig. 6.3. The larval parasitoid, D. rapi, was the dominant parasitoid at both sites, ranging from 1-5 and 1-4 parasitoids/20 cabbage plants at Campania and Kingston respectively. However, no correlation could be established between the abundance of the parasitoids and their larval hosts. No parasitoid of CWB was recorded in any crop at any site. More parasitoids were recorded in months with less sprays.

Figure 6.4. illustrates the trends in numbers of the aphid parasitoid, D. rapae, the hyperparasitoid, A. brassicae and percentage parasitism of aphid populations. Both parasitoids were more abundant at Campania. However, there was no relationship between their seasonal abundance and the percentage parasitism. Both parasitoid numbers and percentage parasitism tended to increase in months receiving relatively less sprays. Parasitoids apparently survived, although in lower numbers, and attacked the residual aphid populations and maintained continuous but low levels of parasitism at Campania. In contrast,

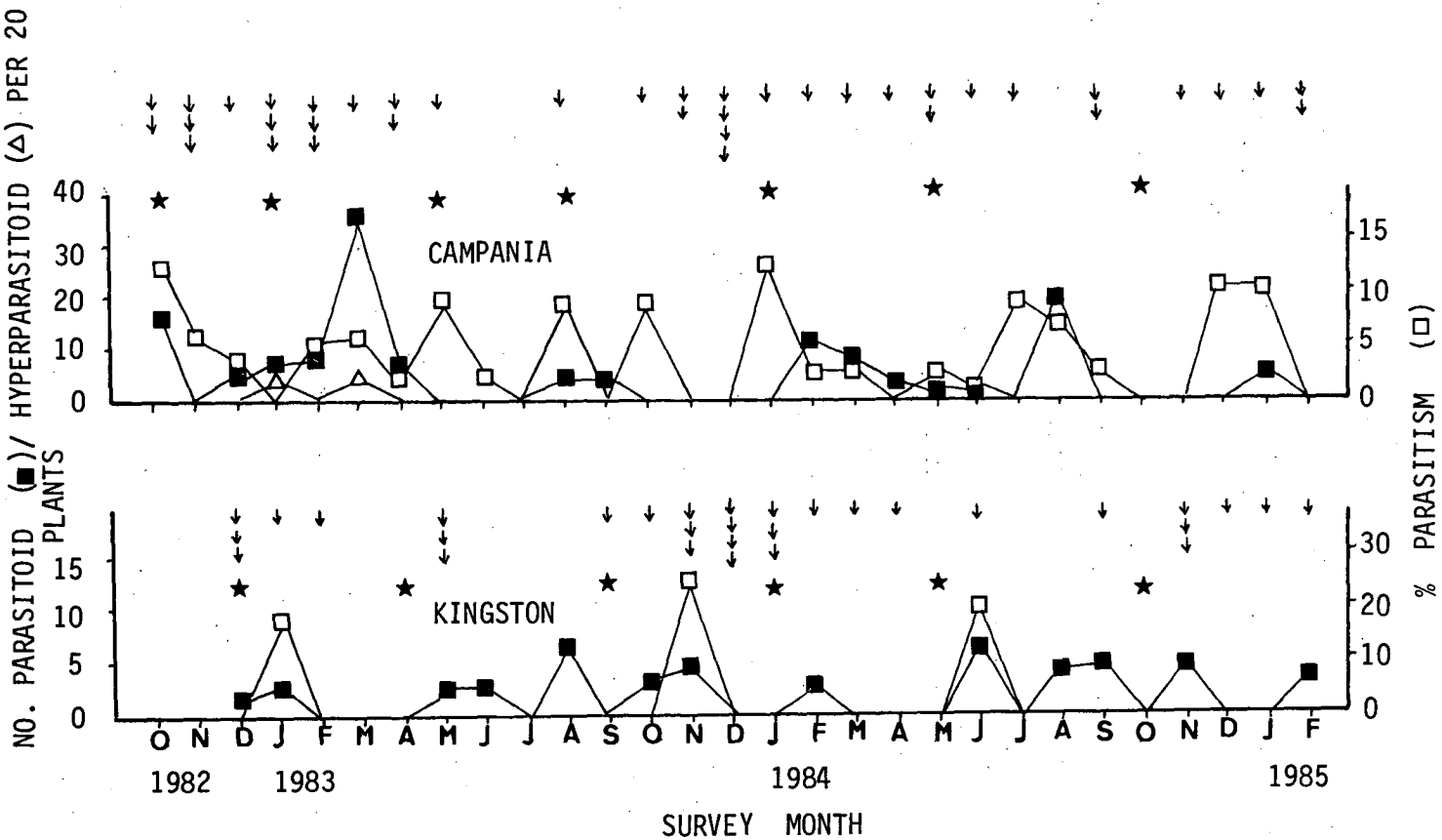



Fig. 6.4. Seasonal abundance of the aphid parasitoid, Diaretiella rapae; hyperparasitoid , Alloxysta brassicae and percentage parasitism of cabbage aphid in commercial cabbage fields at Campania and Kingston. Arrow and star indicate insecticidal spray and new cabbage crop respectively.

percentage parasitism was very low at Kingston.

Trends in the parasitism of CWB and DM larvae are presented in Fig. 6.5. Peak parasitism of both species occured between October-April. Parasitism for CWB larvae ranged 7-25% and 7-20% at Campania and Kingston respectively. Parasitism of DM larvae ranged 10-22 and 7-18% at Campania and Kingston respectively. Figure 6.6 shows the key predatory species recorded on cabbage plants. More predators were found at Campania than at Kingston. As evidenced from sweep net captures, illustrated in Fig. 6.7, more parasitic and predatory species were found at Campania than Kingston. This sampling method was more time efficient than direct counts, however, the trends in numbers of catches were fairly consistent with direct counts. Pitfall trapping employed at Campania was not a successful sampling method as shown also in Chapter 4. Furthermore the traps were very often disturbed by grower's cultural operations.

Modified Moericke traps caught more alate aphids reflecting their higher numbers at Campania than Kingston (Fig. 6.7). However, there was no consistency between the aphid captures and % infested plants or the number of sprays applied at any site.

Pheromone traps for sampling adult DM population were effective in capturing male moths at Campania and Kingston but moth catches were not related to either larval population trends on cabbage plants or the frequency of spraying the crop at any commercial site.

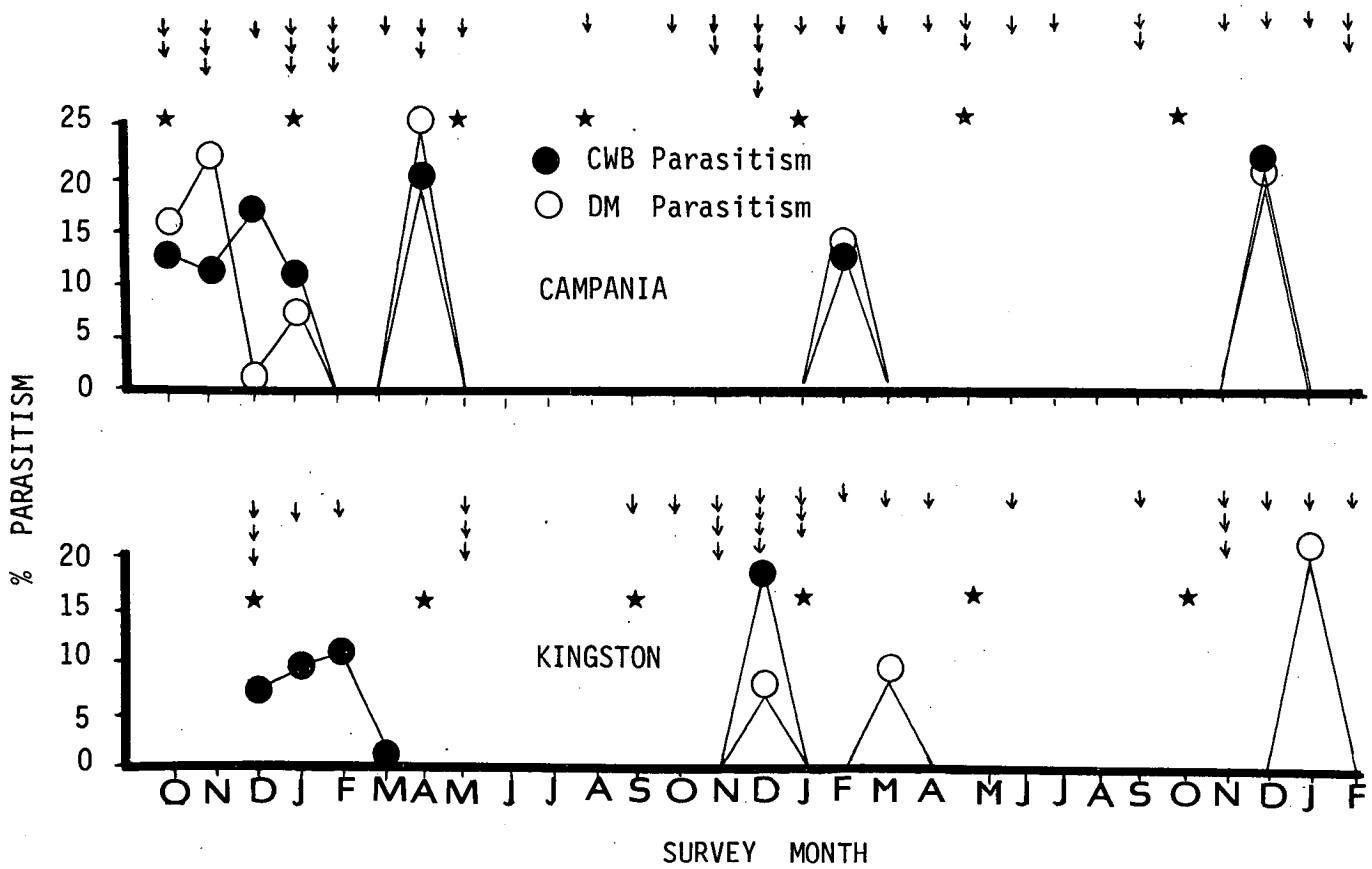



Fig. 6.5. Parasitism of cabbage white butterfly (CWB) and diamondback moth (DM) larvae and schedules of insecticidal spray (↓) in commercial cabbage fields at Campania and Kingston.

★ New crop established.

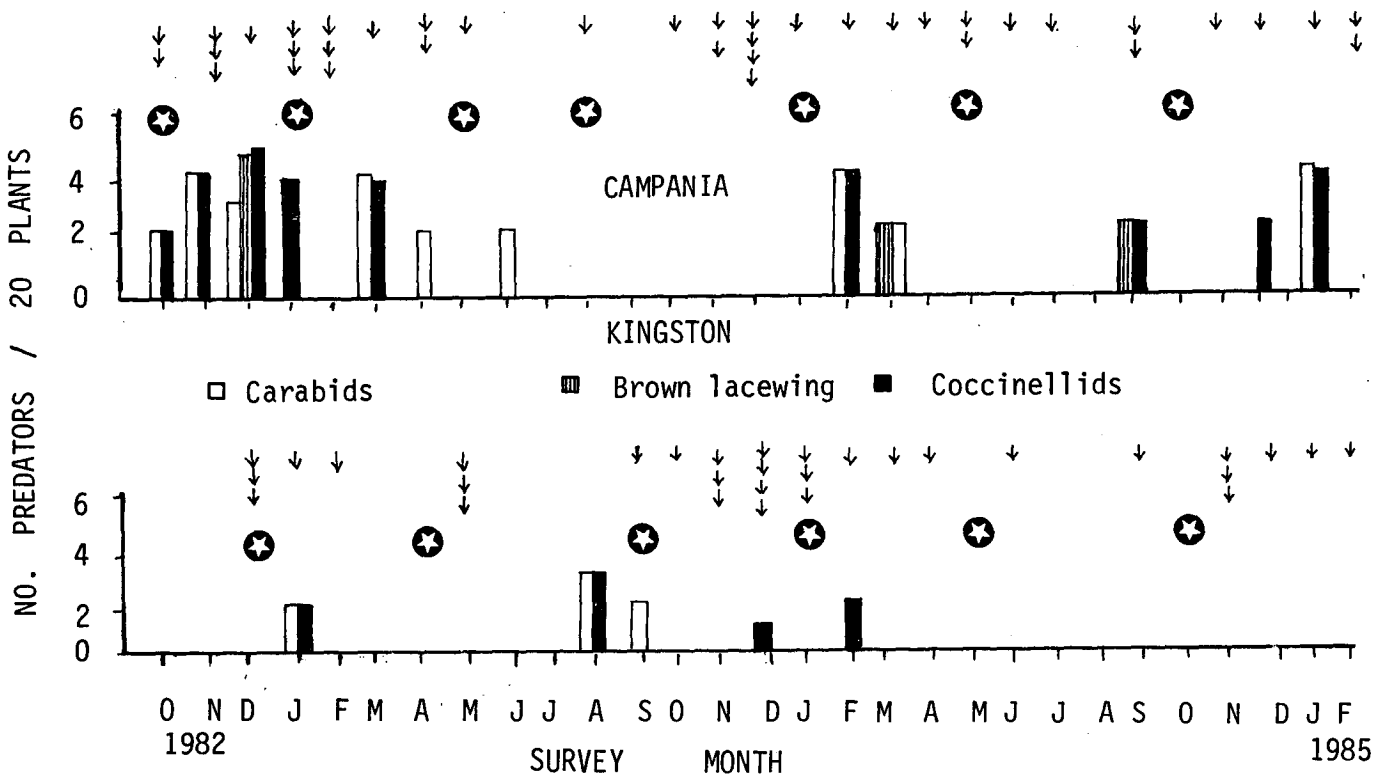



Fig. 6.6. Seasonal abundance of the predators on cabbage plants in commercial cabbage fields at Campania and Kingston. Arrow indicates insecticidal spray.

✪ New crop established.

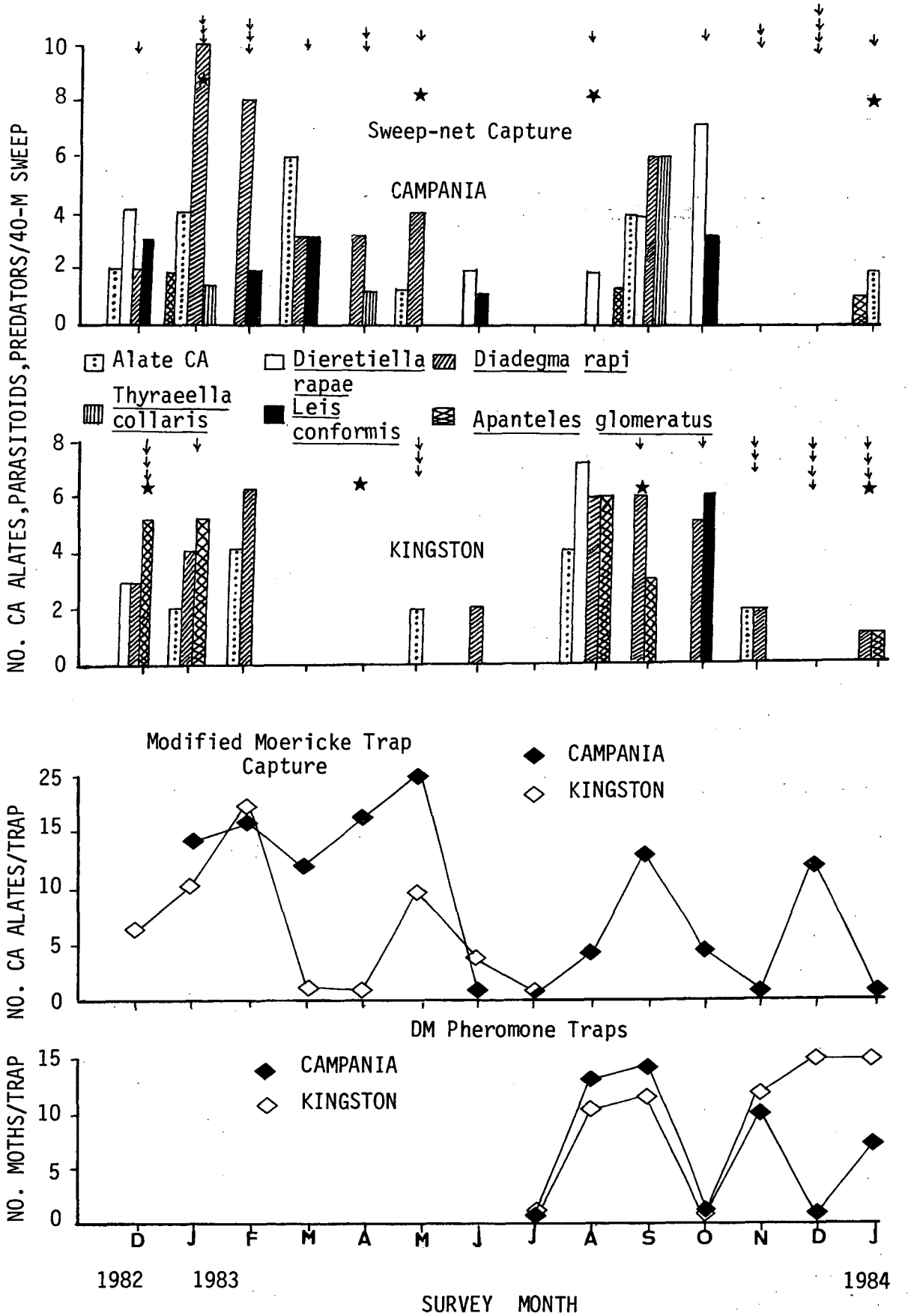



Fig. 6.7. Seasonal trends of the parasitoids and predators of cabbage insect pests on cabbage plants, captures of alate aphids in Modified Moericke traps and DM (adults) in pheromone traps in commercial fields at Campania and Kingston.
★ New crop established. Arrow indicates insecticidal spray.

### 6.3.4 Cost effectiveness of insecticidal schedules in cabbage crops

Tables 6.3, 6.4 illustrate the crop-wise distribution of insecticidal sprays, incurred costs and their effectiveness in terms of final losses in the marketable product.

The grower at Campania used relatively less expensive insecticides but at a higher application frequency compared with the grower at Kingston. However, crop losses were much lower at Kingston than Campania. With few exceptions (crop III) the grower at Kingston was more diligent at the beginning of crop season and applied maximum number of sprays during the early growth stages. In contrast, the grower at Campania applied maximum number of sprays either during the early growth phase or at the crop maturity. The data presented in the Tables 6.3, 6.4 show that both the nature of insecticide and the timing of spray application were the most important factors determining the success of insecticidal schedules.

Less labour/unit crop area was available at Campania than Kingston i.e. 3 men for 45 ha at Campania compared with 1 man for 8 ha at Kingston. This factor resulted in relatively less intensive and less effective farm programme.

Table 6.5 represents the fixed and variable costs involved in cabbage production. The grower at Kingston invariably applied more fertilizer and expensive insecticides compared with the grower at Campania. The calculation of average gross income was based on the

Table 6.3 Insecticidal spray schedules, cost of toxicants and resultant losses in marketable produce at commercial cabbage fields at Campania (1982-85).

| Month | No. sprays | Total sprays/ season | Toxicant(s) used [a] | Cost /ha [b] ($) | Total insecticidal cost/ha/ season ($) | Losses in marketable produce [c] (%) |
|---|---|---|---|---|---|---|
| 1982 * | | | | | | |
| O | 2 | | P | 26.62 | | |
| N | 3 | | R(2) | 26.62 | | |
| | | | R+A(1) | 10.96 | | |
| D | 1 | 6 | P | 13.31 | 77.51 | 4.5(44) |
| 1983 | | | | | | |
| J * | 3 | | L+R(2) | 29.10 | | |
| | | | P(1) | 13.31 | | |
| F | 3 | | E+A | 41.43 | | |
| M | 1 | | E+A | 13.81 | | |
| A | 2 | 9 | E+A(1) | 13.81 | 124.77 | 3.3(30) |
| | | | | 13.31 | | |
| M * | 1 | | E | 12.00 | | |
| J | 0 | | - | - | | |
| J | 0 | | - | - | | |
| A | 1 | 2 | L | 45.60 | 57.60 | 2.5(40) |
| S * | 0 | | - | - | | |
| O | 1 | | E+L | 17.40 | | |
| N | 2 | | E+A | 27.62 | | |
| D | 4 | 7 | E+A | 55.24 | 100.25 | 3.3(30) |
| 1984 | | | | | | |
| J * | 2 | | E+A | 27.62 | | |
| F | 0 | | - | - | | |
| M | 1 | | E | 12.00 | | |
| A | 1 | 4 | E+A | 13.81 | 53.43 | 8(50) |
| M * | 2 | | E+A(1) | 13.81 | | |
| | | | R+1(1) | 10.96 | | |
| J | 1 | | R+A | 10.96 | | |
| J | 1 | | R+A | 10.96 | | |
| A | 0 | | - | - | | |
| S | 2 | 6 | R+A | 21.92 | 68.61 | 30(50) |
| N * | 1 | | R+A | 10.96 | | |
| D | 1 | | R+A | 10.96 | | |
| 1985 | | | | | | |
| J | 1 | | R+A | 10.96 | | |
| F | 2 | 5 | R+A | 21.92 | 54.80 | 4(100) |
| Total 7 | 39 | | | | 536.97 | |

* - New crop

a - Toxicants abbreviated as A...Ambush (permethrin), E...Ekatin (thiometon), L...Lannate (methomyl), P...Phosdrin (mevinphos), R...Rogor (dimethoate). Values in parentheses represent the number of spray application(s) when more than one insecticidal sprays were employed in a month.

b - Excluding application cost : 1 spray @ 0.5 hour/ha @ $5.70/hour

c - Only losses due to insect infestation/injury were considered. Values in parentheses represent the number of plants examined at maturity/harvest.

Table 6.4 Insecticidal spray schedules, cost of toxicants and resultant losses in marketable produce at commercial cabbage fields at Kingston (1982-85).

| Month | No. sprays | Total sprays/ season | Toxicant(s) used [a] | Cost/ha ($) [b] | Total insecticidal cost/ha/ season ($) | Losses in marketable produce (%) [c] |
|---|---|---|---|---|---|---|
| 1982 | | | | | | |
| D * | 3 | | L+M(2)<br>L (1) | 36.20<br>22.80 | | |
| 1983 | | | | | | |
| J | 2 | | L | 45.60 | | |
| F | 0 | | - | - | | |
| M | 0 | 5 | - | - | | |
| A * | 0 | | - | - | 104.60 | 3.3(30) |
| M | 3 | | LB(2)<br>E (1) | 45.60<br>12.00 | | |
| J | 0 | | | | | |
| J | 0 | | | | | |
| A | 0 | 3 | | | 57.60 | 0.0(50) |
| S * | 1 | | LB | 22.80 | | |
| O | 1 | | LB | 22.80 | | |
| N | 3 | | L | 68.40 | | |
| D | 4 | 9 | L | 91.20 | 205.20 | 1.0(100) |
| 1984 | | | | | | |
| J * | 3 | | L | 68.40 | | |
| F | 1 | | L | 22.80 | | |
| M | 1 | | L | 22.80 | | |
| A | 1 | 6 | LB | 22.80 | 136.80 | 4.0(50) |
| M * | - | | - | - | | |
| J | 1 | | M | 15.20 | | |
| J | - | | - | - | | |
| A | - | | - | - | | |
| S | 1 | 2 | L | 22.80 | 38.00 | 2.0(100) |
| O * | - | | - | - | | |
| N | 3 | | LB | 68.40 | | |
| D | 1 | | LB | 22.80 | | |
| 1985 | | | | | | |
| J | 1 | | LB | 22.80 | | |
| F | 1 | 6 | LB | 22.80 | 136.80 | 2.0(50) |
| Total 6 | | 31 | | | 679.00 | |

* - New crop

a - Toxicants abbreviated as E...Ekatin (thiometon), L...Lannate (methomyl), LB...Lorsbane (chlorpyriphos), M...Metasystox (demeton-s-methyl). Values in parentheses represent the number of spray application(s) when more than one insecticidal sprays were employed in a month.

b - Excluding application cost : 1 spray @ o.5 hours/ha @ $5.70/hour

c - Only losses due to insect infestation/injury were considered. Values in parentheses represent the number of plants examined at maturity/harvest.

Table 6.5 Economic profile of commercial cabbage production at Campania and Kingston.

| Factor/Input | Rate/cost per unit | $/ha Campania | Kingston |
|---|---|---|---|
| Fixed Costs | | | |
| Tillage (Land preparation etc.) | 6 hrs/ha @ $5.0/ha | 30.00 | 30.00 |
| Transplanting | 30 man hrs @ 5.30/ha | 159.00 | 159.00 |
| Harvesting | 200 man hrs @ 5.50/ha | 1100.00 | 1100.00 |
| Total fixed costs | | 1289.00 | 1289.00 |
| Variable Costs | | | |
| Seed | 250-300g/ha Greengold cv. @ $ 540/kg | 148.50 | 148.50 |
| Fertilizer | Complex 3:6:8 + Molybdate @ 250kg/ha (Campania), 300 kg/ha (Kingston) @ $ 172/t + $7.5/t as cartage/20km | 46.75 | 53.85 |
| Irrigation | 14 hrs/ha @ $2.00/ha from Cole river+pumping cost @ $2.50/hr | 63.00 (water charges +) pumping cost) | 35.00 (pumping cost from site dam) |
| Insect pest control | ca. per/ha/season | 76.61 | 113.16 |
| Crop losses | ca.losses due to insects/ha/season | 428.75 | 110.70 |
| Transport (cartage etc.) | $7.5/t/20km for 18t/ha | 270.00 | 135.00 |
| Miscellaneous (casual labour,) weeding, fertilizer spreading etc.) | Av. 48 man hrs @ $5.50/ha | 264.00 | 264.00 + family help |
| Total variable costs | | 1297.61 | 860.21 |
| Total costs | | 2586.61 | 2149.21 |
| Gross margin | Av. gross income-total cost (Av.gross income= 19 t@30c/kg) | 5700-2586.61 = 3113.39 | 5700-2149.21 = 3550.79 |

average yields reported by the farmers and could be biased. However, considering the crop losses due to insects the gross margin received by the grower at Kingston was higher than the gross margin received by the grower at Campania.

Table 6.6 summarizes the technical attributes of the growers at both sites.

Table 6.6 Technical attributes of commercial cabbage growers at Campania and Kingston.

| Attributes | Campania | Kingston |
|---|---|---|
| Size of property (ha) | 45 | 8 |
| Crop importance [a] (%) | 25 | 21.4 |
| Market outlet | Contract with retail stores | Wholesale market agents |
| Grower's objective | Maintain supply to contractors | Maximization of profit |
| Perception of pest damage | Scheduled, non systematic, mainly based upon previous experience of the farm manager | Random check |
| Irrigation source and methodology | Cole river, site dam often with line sprinkler. Frequent water shortages | Site dam, overhead wheel sprinkler. No water shortage |
| Varietal preference (Frequency of cropping) | Greengold<br>Ballhead hybrid<br>Savoy King<br>Red Pickling<br>Dutch hybrid | Greengold<br>Beauty<br>Ballhead hybrid<br>Terrific<br>Climax |
| General attitude | Traditional | Innovative |
| Labour requirements | Continuous | Occasional |

a: Crop importance (%) = $\frac{\text{Acreage of cabbage crop}}{\text{Total acreage of crops / year}}$ X100

## 6.4 Discussion

All insecticides applied to protect cabbage crops from insect pest attacks were registered domestically for effective and safe pest control (Anon, 1981) however, despite increased insecticidal usage, considerable losses in the marketable product particularly at Campania demonstrated lack of adequate information by the decision-maker (grower) as to when and what to apply to minimize such losses. Growers were forced into the pursuit of short-term commercial objectives by high cosmetic standards for produce set by the whole-sale agents, retailers and the consumers. Based upon their previous experience they had fixed and critical periods when pest attack would be particularly damaging and deleterious to crop revenue. Cyert and March (1963) categorized this strategy as trial and error through which satisfactory control was achieved through the rejection of the strategy which proved unsatisfactory in the past. Norton (1976) considered that the grower's decision of pest control measures was determined by 4 factors, i.e.

(a) the farmer's objective,
(b) his perception of pest attack and resultant damage,
(c) control measures available to him and
(d) decision rules by which he operates.

Both at Campania and Kingston the crops were often sprayed when there was no need to do so. As the pest attack was not monitored the spray applications were

poorly timed. Stern et al. (1959) stressed that control measures should be applied only when it is profitable to do so. Geier et al. (1983) emphasized that market oriented aspects guide the choice of control procedure and due to imminent market competition growers are compelled to spray to maintain zero infestation levels particularly at or near harvest. The trends in spray timing at Campania support this argument. However, at Kingston the higher frequency of sprays during initial growth stages accounted for production oriented aspects and the grower's main objective was maximization of crop revenue.

Campania is surrounded by Sorrel and Richmond where brassica forage crops are grown to meet the needs of stock during periods of the year when pasture growth is insufficient (Mr. David Secomb, Tas. Dept. of Agriculture, Pers. comm., 1983, cf. Appendix 3.4). These crops are rarely sprayed and undoubtedly acting as a prime source of insect pests. It could be reasonably expected that under favourable environmental conditions the pest population may have the capacity to disperse from the harvested crops to newly cultivated habitats. Wheatley and Finch (1984) considered that a resident population temporally at very high levels could infest the neighbouring brassica crops during their susceptible stage of development.

After harvest, the stubbles/crop residues were always left in the field at both commercial sites. The regrowths from cut stems were not sprayed and usually harboured very high pest levels which continuously invaded adjacent

crops. This phenomenon was found to be responsible for intensifying spray schedules.

The study demonstrated that some of the cheaper insecticides used by the grower at Campania were not performing adequately for CA control. However, this could be misleading because no untreated (control) plants were available for comparison. This grower was also concerned about the inadequate control of aphid infestations.

There was also an evidence that water shortage or irrigation methods were related to pest build ups. The grower at Campania faced frequent shortages of water whereas at Kingston an optimum supply of water was maintained throughout the year. Furthermore an overhead movable sprinkler used by the grower at Kingston was observed to be severly "washing" the cabbage plants. This frequent washing was also involved in the suppression of pest stages on cabbage plants. Likewise, Nakahara et al. (1985) discovered in Hawaii that intermittent overhead irrigation effectively suppressed field populations of the DM without insecticides. They reported that this sprinkler system may control moth populations by disrupting mating and oviposition. Similar findings were reported by Talekar et al. (1985) in Taiwan and Tabashnik and Mau (1986) in Hawaii. Wearing (1972 b) suggested that continuous irrigation would reduce the rate of increase of aphids. At Campania line sprinkling system was used which was very mild compared with the overhead sprinkler at Kingston.

Growers invariably resorted to relatively heavy schedules of insecticides after transplanting which as a

consequence did not allow the natural enemies (parasitoids and predators) to establish at the beginning of the season. The continuity of sprays prevented further increase of natural enemies. On many sampling occasions parasitoids and predators were found dead on the cabbage plants, yet the impact of the insecticides on natural enemies remains unappreciated. Growers did not regard natural enemies of any consequence. Wearing (1982) highlighted this problem as a technical obstacle faced because of low pest tolerances in horticultural crops i.e. 100% control which may not be possible with the help of natural enemies only. This study also highlights the difficulty in using biocontrol agents under present socio-economic conditions and emphasizes the importance of proper extension advice in pest control.

There is no doubt that in the absence of pest control insects could cause substantial damage but it is also true that some cabbage crops at certain growth stages suffered insignificant attack and did not require spraying. Another limitation was the ever fluctuating market price of the marketable produce which ranged from 40-75 cents per cabbage head.

The results further point out that variation between growers in the usage of insecticides was the outcome of an interplay between their individual perceptions and objectives as well as their operational constraints (see also Norton, 1976). In this study two barriers limiting the efficiency of currently available pest control strategeis were noted;

(a) a lack in understanding or a limited perception of pest damage and

(b) difficulties in decision-making.

Proper monitoring of pest population to determine the need and extent of chemical control should be a first approach for effective pest suppression in cabbage crops. A beneficial consequence of this study was that regular monitoring of crops and destruction of crop residues became part of the grower´s programme.

# CHAPTER 7

# EVALUATION OF DIFFERENT SPRAY PROGRAMMES AND THEIR EFFECTS ON INSECT PESTS, NATURAL ENEMIES AND CABBAGE YIELD

## 7.1 Introduction

The application of integrated control procedures against insect pests of cabbage has not been considered experimentally in Australia. Most overseas studies (e.g. Chalfant, 1979; Chalfant et al., 1979; Eckenrode et al., 1981; Simonet and Morisak, 1982) have emphasized kinds of insecticidal compounds and application frequencies with little attention to their effects on beneficial organisms. The objectives of this study were to evaluate :

(a) the relative efficiency of ;
    (i) intensive, regular sprays,
    (ii) a commercial spray programme and
    (iii) spray schedules including both chemical and microbial pesticides.
(b) the use of chemical pesticide sprays only at times when pest densities reached a predetermined density or action threshold,
(c) the effect of different numbers of spray applications according to the growth stages of cabbage and
(d) the effectiveness of chemical and microbial pesticide sprays applied either on the basis of stage of plant development or action threshold.

## 7.2 Materials and Methods

All experiments were conducted at S.J.F. College using plots of Ballhead hybrid cabbage plants. Four-week old seedlings were transplanted into 3x3 m plots. Plants were spaced 0.5 m apart. Each plot contained 25 plants (5x5) and plot to plot distance was 1 m.

Treatments were established using a 15 l capacity Tris knapsack sprayer (Birchmeir and Cie Ag. Ltd., CH-3444 Künten) with an operating pressure of 3.1 kgcm to deliver a 120 spread of spray at a rate of 475 l/h. Two passes of each plant/row were made by spraying up and down the rows. The experimental design was of randomized complete blocks and there were 6,6,3,4 replicates per treatment in experiments I,II,III and IV respectively.

Marketability of cabbage was assessed at harvest using the method of Greene et al. (1969) (cf. Chapter 6). In practice the assessment involved the allocation of a quantitative value from a score of 1-6 by examination of the head and 4 wrapper leaves. Marketable heads, scoring 1-3, consisted of cabbage with undamaged heads or heads whose marketability could be restored by removal of a single leaf. Feeding holes ($\geqslant$3.00 mm) were counted to rank damage in 2-6 scores. Cabbage heads were weighed with and without wrapper leaves and roots were harvested, washed free of soil, surface dried and weighed.

Analysis of data was done by analysis of variance using a computer programme (ANOVA Version 1.1 Human Systems Dynamics 1983, U.S.A) following transformation of percentage data to arcsine values (Zar, 1974). Treatment

means (gross weight, marketable head weight, percent marketable heads, etc., were compared by Duncan's multiple range test (Duncan, 1955; Harter, 1960). Three distinct facets of each treatment, evaluated in each experiment, were:

a. the effect of spray applications on pest populations,
b. the effectiveness of the treatments in reducing plant damage and increasing marketability of cabbage heads and
c. the impact of the treatments on natural enemies.

### 7.2.1 Experiment 1. Evaluation of intensive, commercial and integrated control procedure (1982-83)

The treatments consisted of:

(i) intensive and regular sprays applied to suppress pest numbers and thereby favour precise pest free cabbage growth,
(ii) a programme employing insecticides commonly recommended and currently utilized by commercial growers and
(iii) a combination in which chemical insecticide was used to suppress aphids but a bacterial formulation, Dipel, was employed against larvae of CWB and DM.

The treatments and spray application frequency are shown in Table 7.1.

Table 7.1 Comparative spray treatment programme against cabbage pests at S.J.F. College, cabbage crop (Summer 1982-83).

| Spray Schedule | Treatment x | Dosage kg.A.I/ha | Frequency |
|---|---|---|---|
| Intensive | Maldison E.C. + demeton-s-methyl E.C. | 1.0 + 0.50 | Weekly |
| Commercial | Permethrin E.C. | 0.10 | Biweekly |
| Integrated | Dipel W.P. + Pirimicarb W.P. | 0.60 + 0.30 | Biweekly |
| Nil | Water only | - | Biweekly |

x Teepol (0.01% v/v) was included in each spray as a sticker

7.2.1.1 Results

Trends in the numbers of CA, CWB eggs and larvae and DM larvae within treatments are shown in Fig. 7.1. Intensive sprays with maldison+demeton-s-methyl successfully suppressed all pests but caused slight phytotoxicity. In contrast, reductions in pest numbers following the commercial schedules resulted in pest resurgences within the spraying interval of 14 days. Both the intensive and commercial treatments favoured greater oviposition by CWB females but suppressed larvae of CWB and DM more effectively than integrated treatments. The integrated treatments provided good control of CWB larvae but gave little suppression of DM larvae compared with other treatments.

Fig. 7.2 shows the proportional infestations of cabbage plants at different growth stages under the different treatments. Infestation (% infested plants) by

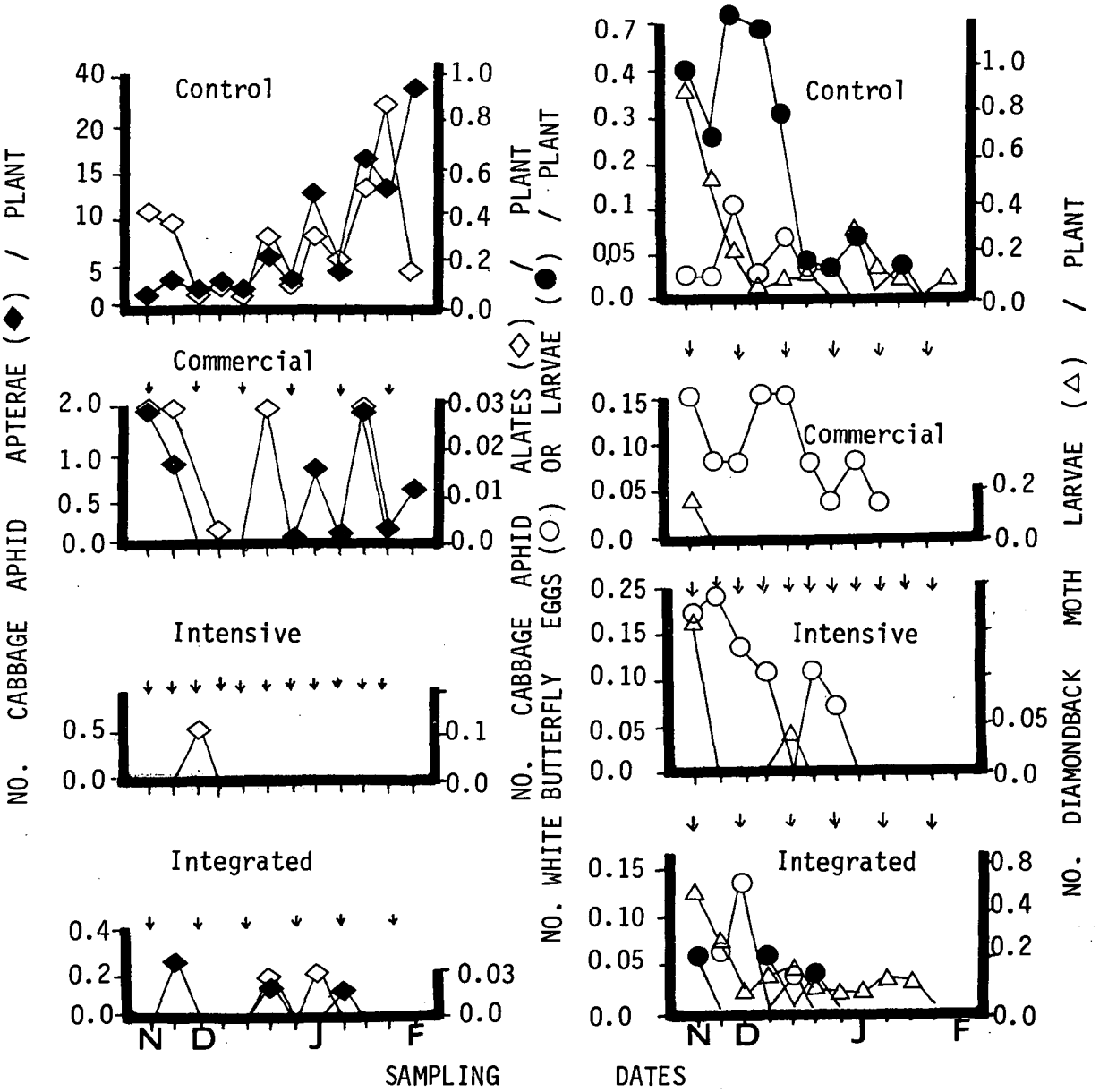



Fig. 7.1. Populations of cabbage aphid, white butterfly eggs and larvae and diamondback moth larvae in plots of cabbage treated with chemical or microbial insecticides at S.J.F. College (1982-83).Spray material and timing of application corresponds to:

Control = Untreated
Commercial = Permethrin
Intensive = Maldison + demeton-s-methyl
Integrated = Dipel + pirimicarb

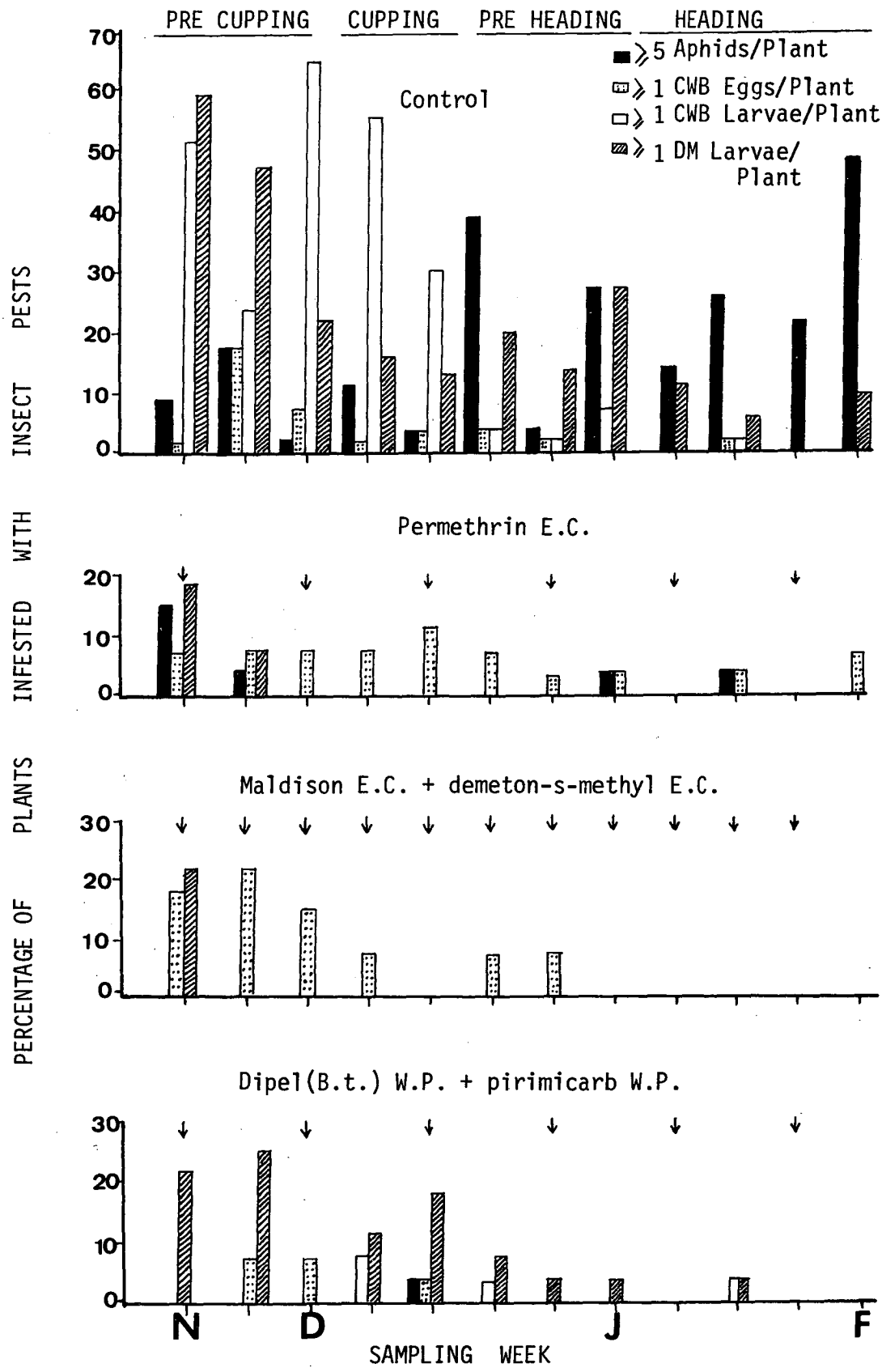



Fig. 7.2. Percentage of cabbage plants infested with pests under different insecticidal treatments at S.J.F. College (1982-83). Arrow indicates spray application.

CWB and DM larvae decreased in time in all treatments and untreated plots. The trends in aphid infested plants showed that aphid infestation tended to exclude the infestations by CWB and/or DM larvae. Similar trends were obtained between CWB and DM larval infestations.

Greater numbers of key and potential natural enemies were recorded/captured in the untreated plots than treated plots (Fig. 7.3). Sum totals of natural enemies in different treatments ranked untreated> integrated> commercial> intensive.

The damage ratings and yields of the different treatments are presented in Table 7.2. Untreated plots received significantly ($P=0.05$) higher damage than all other treatments. There were no significant differences ($P>0.05$) in gross yields and root weights between treated and untreated plots. No significant difference was found in the average weight of marketable heads among treated plots however, the mean weight of marketable heads in commercial treatment plots was significantly higher than in untreated plots.

There were no significant differences in the marketable yields obtained from different treatments but the yields from treated plots were significantly greater than untreated controls. Damage ratings in all plots were negatively correlated to marketability ($P<0.01$, $r = -0.94$, Fig. 7.4).

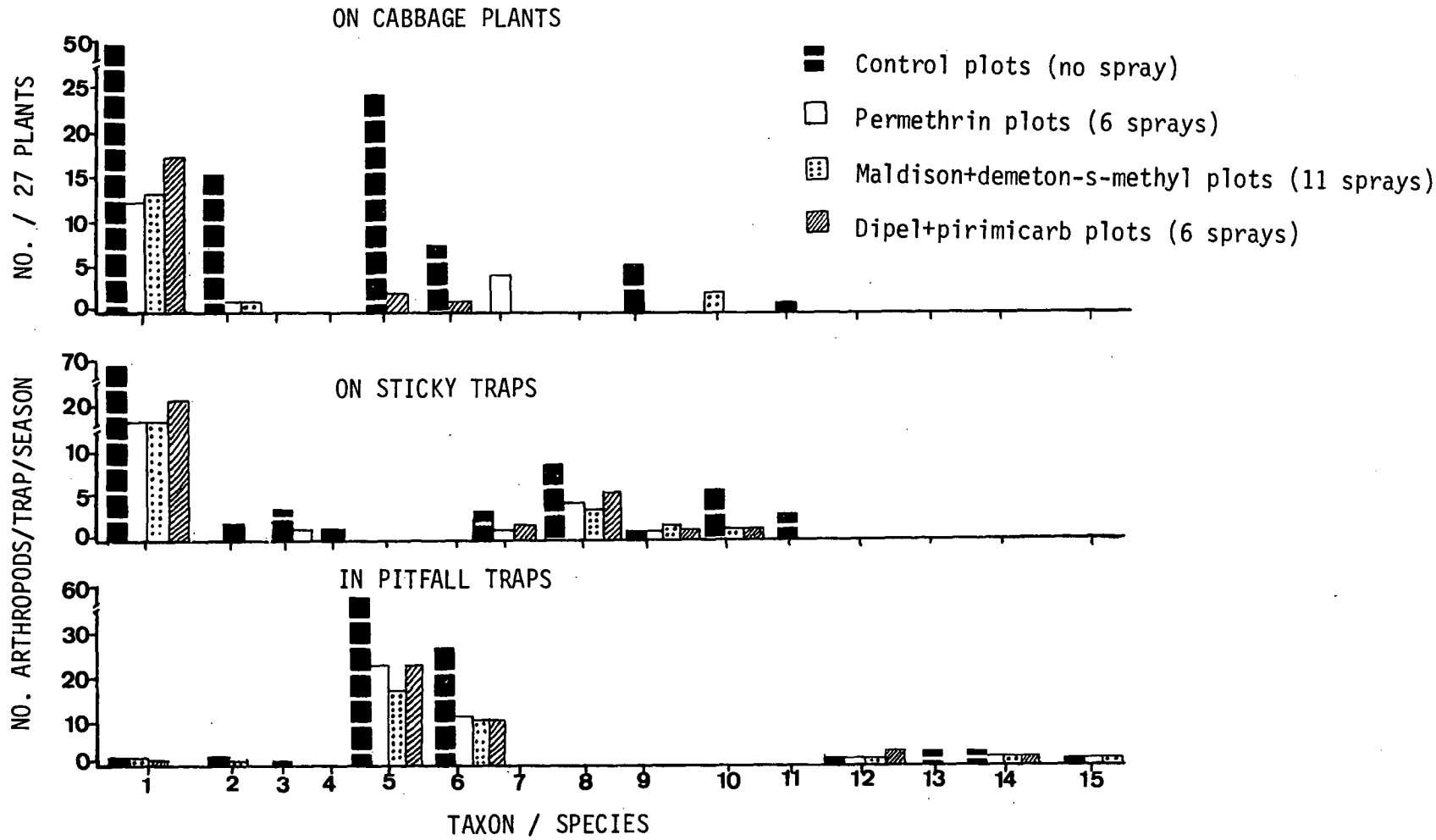



Fig. 7.3. Total number of key parasitoids and potential predators recorded on cabbage plants or caught in sticky or pitfall traps in cabbage crop at S.J.F. College (1982-83).Taxon/species are numbered as : 1...Diaeretiella rapae; 2...Brown lacewing; 3...Coccinellids; 4...Syrphids; 5...Ants; 6...Spiders; 7...CWB larval parasitoid; 8...CWB pupal parasitoid; 9...DM larval parasitoid(D. rapi); 10...DM pupal parasitoid; 11...DM larval parasitoid(A. plutellae); 12...Carabids; 13...Staphylinids; 14...Centipedes/millipedes; 15...Pentatomids.

Table 7.2 Qualitative and quantitative evaluation of insecticidal treatments on damage rating, yield and cost of control in cabbage plots at S.J.F. College (Summer 1982-83).

| Treatment & rate of application Kg.A.I/ha | No. of Sprays | Mean damage rating [X] | Yield | | | | Total Toxicant cost $/ha [*] |
|---|---|---|---|---|---|---|---|
| | | | Gross yield kg / plant | Mean head weight kg / plant | Mean root wt. (g). | Marketable yield % | |
| | | [Y] | | | | | |
| Permethrin E.C. 0.10 | 6 | 0.76a | 1.78 | 0.97a | 102.2 | 70a | 78.0 |
| Maldison E.C. + demeton-s-methyl E.C. 1.0 + 0.5 | 11 | 0.77a | 1.55 | 0.83ab | 118 | 62a | 124.74 |
| Dipel (B.t.) W.P. + pirimicarb W.P. 1.0 + 0.3 | 6 | 0.97a | 1.41 | 0.71ab | 94 | 42b | 188.28 |
| Control(untreated) | - | 1.79b | 1.29 N.S. | 0.57b | 103 N.S. | 18.6c | - |

X Based on 1-6 scoring system of Greene et al., (1979).

Y Means followed by the same letters in each column are not significantly different ($P \geq 0.05$) when tested by Duncan's new multiple range test. N.S. Not significant ($P \geq 0.05$).

* Toxicant costs were obtained from M/S Hopkins Pty., Hobart (1985). Application costs excluded.

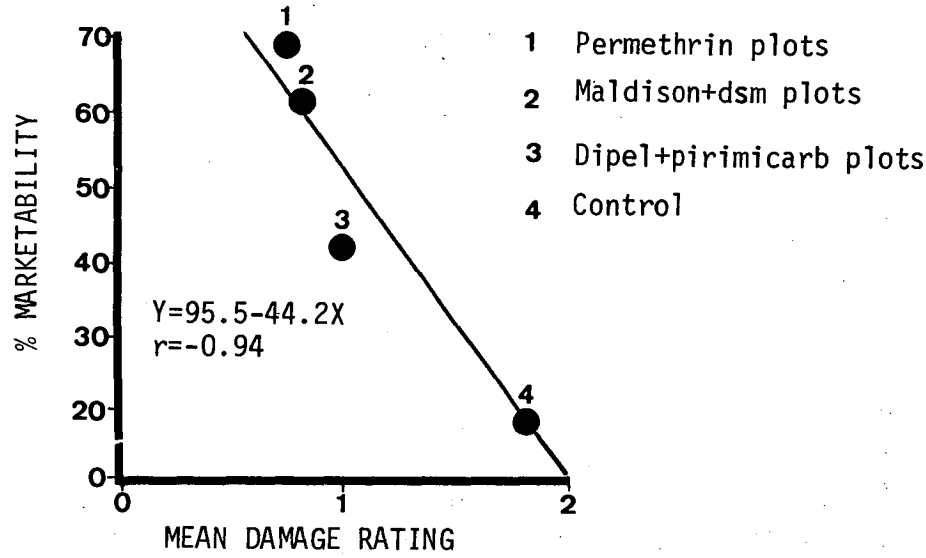



Fig. 7.4. Relationship between mean damage rating of cabbage plants at harvest and percent marketability of cabbage heads.

### 7.2.2 Experiment 2. Evaluation of insecticides applied according to need (1983).

This experiment evaluated the use of insecticides, singly or in combination, only when the pest numbers achieved certain predetermined levels or action thresholds (e.g. Greene, 1972; Shepard, 1973; Kennedy and Oatman, 1976; Simonet and Morisak, 1982; Trumble et al., 1982). In practice, plants were only sprayed when CA and CWB and/or DM larval mean densities were >5 and >0.1 per plant, respectively.

Pirimicarb was selected for aphid control whereas permethrin, maldison and Dipel were used against lepidopterous larvae. Formulations and dosages are given in Table 7.3. Methiocarb granulated baits were used to suppress attacks by slugs and snails.

7.2.2.1 Results

The effectiveness of different sprays against CA, CWB and/or DM larval populations are summarized in Figs. 7.5, 7.6. Aphid populations were suppressed by all treatments relative to the untreated plots but with periodic resurgences.

The systemic pirimicarb plus Dipel sprays effectively suppressed aphids and CWB larvae but not DM larvae. As experienced in the previous experiment spraying enhanced oviposition by CWB.

Among the treated plots, numbers of natural enemies were the greatest in the Dipel plus pirimicarb plots followed by permethrin plus pirimicarb and maldison plus pirimicarb (Fig. 7.7). Greater numbers of natural enemies were recorded in untreated plots than the treated plots. Significantly lower damage levels and more marketable heads were obtained in treated plots than in untreated plots. However, gross yields in treated and untreated plots were not significantly different (Table 7.3).

The number of sprays applied to maintain aphids and larval populations below action thresholds were 4,5, and 7 for the permethrin plus pirimicarb (treatment 1), maldison plus pirimicarb (treatment 2) and Dipel plus pirimicarb (treatment 3) respectively. Mean damage ratings, in treated and untreated plots, were negatively correlated ($r=-0.929$) with percent marketable heads (Fig. 7.8).

From a practical point of view the treatments 1 and 2 were equally cost effective in comparison to treatment 3 which cost ca. 2.5 times more for a poorer result.

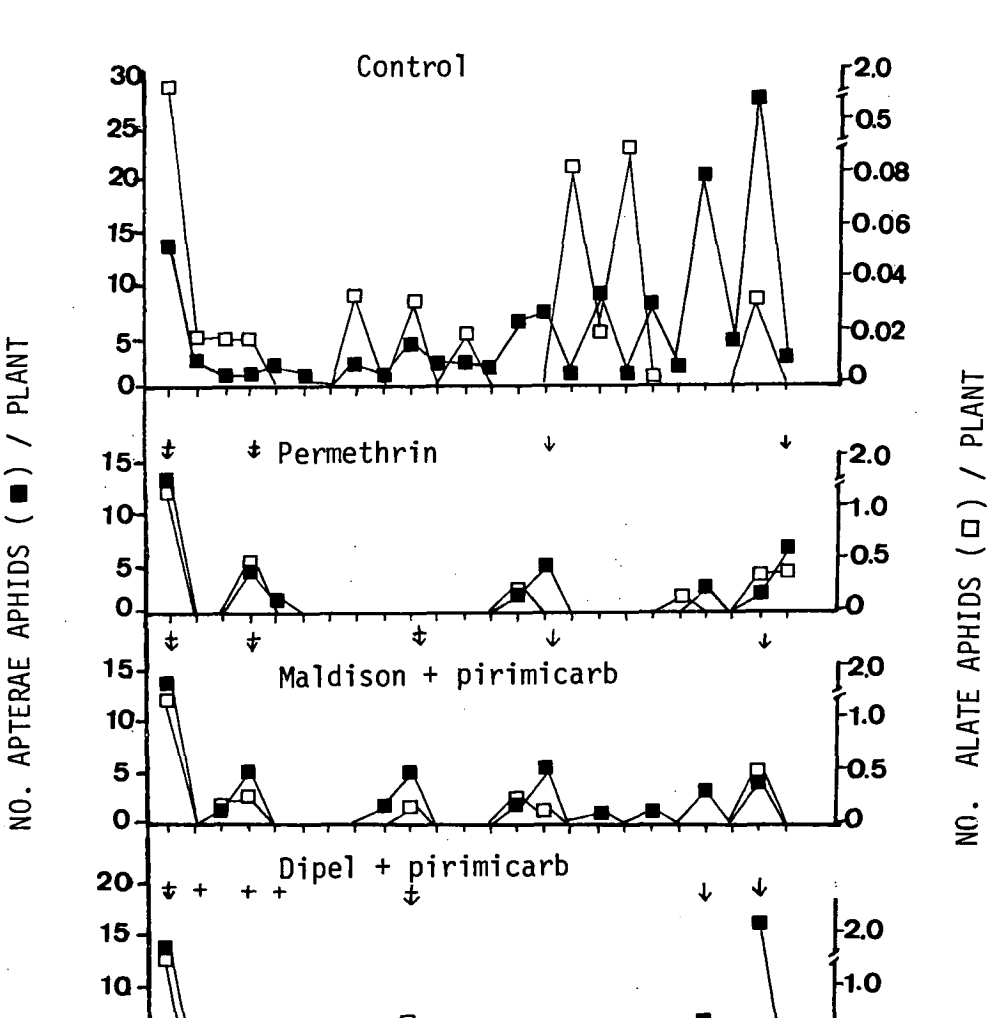



Fig. 7.5. Populations of cabbage aphid (apterae, alate) in plots of cabbage treated with combination (ǂ) (chemical and/or microbial) or single insecticide (+,↓) at S.J.F. College (1983).
ǂ =Insecticide spray against aphids and CWB/DM larvae;
+/↓ =Insecticide spray against aphids or CWB/DM larvae, respectively.

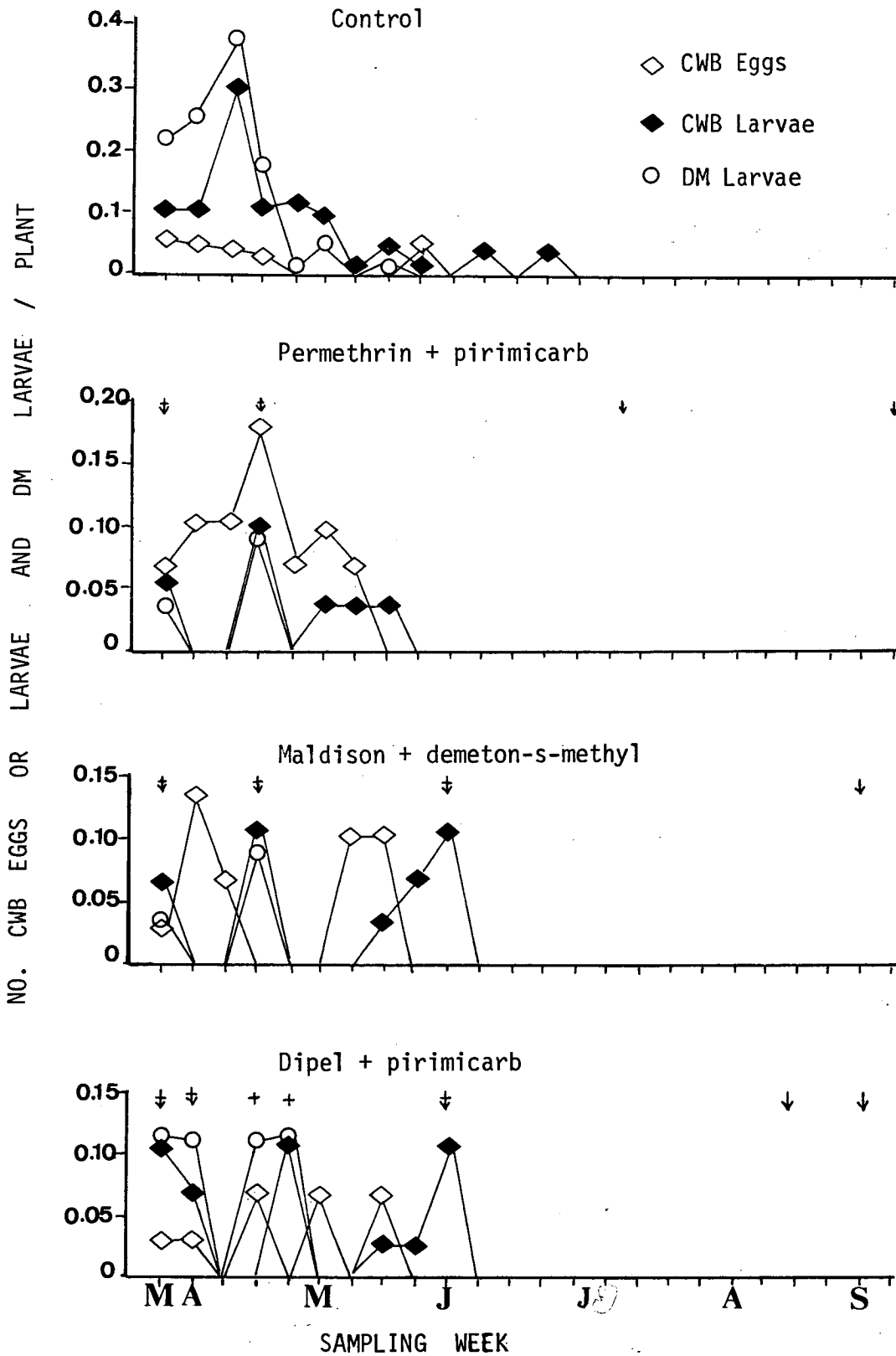



Fig. 7.6. Populations of CWB eggs and larvae and DM larvae in plots of cabbage treated with chemical or microbial insecticides at S.J.F. College (1983).
↡ Spray application with combination of insecticides against aphids and CWB/DM larvae ;
↓ Single insecticide application against aphids ;
+ Single insecticide application against CWB/DM larvae.

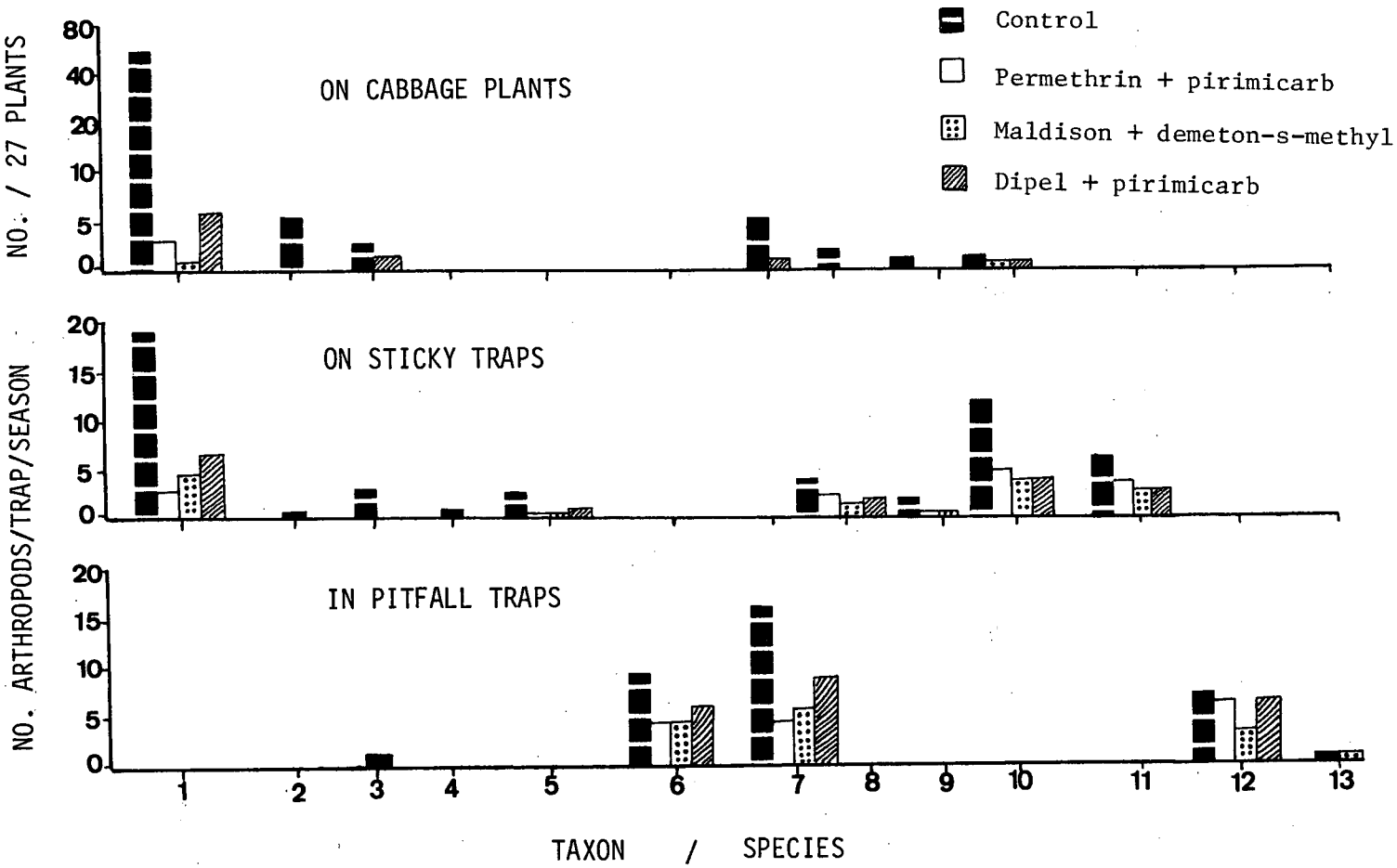



Fig. 7.7. Total number of key parasitoids and potential predators recorded on cabbage plants or caught in sticky or pitfall traps in cabbage crop at S.J.F. College (Mar.83-Sep.83). Taxon/species are numbered as : 1...Diaeretiella rapae; 2...Alloxysta brassicae; 3...Brown lacewing; 4...Coccinellids; 5...Syrphids; 6...Ants; 7...Spiders; 8...CWB larval parasitoid; 9...CWB pupal parasitoid; 10...DM larval parasitoid; 11...DM pupal parasitoid; 12...Centipedes + millipedes; 13...Carabids and staphylinids.

Table 7.3 Qualitative and quantitative evaluation of insecticidal treatments on damage rating, yield and cost of control in cabbage plots at S.J.F. College (Winter, 1983) X.

| No. | Treatment & rate of application kg A.I./ha | No. spray application | Mean damage rating Y | Yield: Gross yield kg / plant | Yield: Mean head weight kg/plant | Yield: Marketable heads % | Total Toxicant cost $/ha |
|---|---|---|---|---|---|---|---|
| | | | | | Z | | |
| 1 | Pirimicarb 0.3 | 2 | 1.98a | 0.79 | 0.51a | 69.3a | 15.66 |
| | Permethrin+ pirimicarb 0.1 + 0.3 | 2 | | | | | 41.61 |
| | | | | | | | 57.27 |
| 2 | Pirimicarb 0.3 | 2 | 2.15a | 0.79 | 0.48ab | 56.0ab | 15.66 |
| | Maldison + pirimicarb 1.0 + 0.3 | 3 | | | | | 44.25 |
| | | | | | | | 59.91 |
| 3 | Pirimicarb 0.3 | 2 | 2.75a | 0.62 | 0.34b | 43.8b | 15.66 |
| | Dipel 1.0 | 3 | | | | | 70.50 |
| | Dipel + pirimicarb 1.0 + 0.3 | 2 | | | | | 62.74 |
| | | | | | | | 148.90 |
| 4 | Control (untreated) | - | 3.90b | 0.59 N.S. | 0.32b | 36.6c | - |

X = Each treatment evaluated weekly and sprayed when lepidopterous larvae and/or cabbage aphid > 0.1 larvae and/or 5 aphids per plant respectively.

Y = Based upon a 1-6 damage scale of Greene *et al*. (1979)

Z = Means followed by the same letters in each column are not significantly different ($P \geq 0.05$, Duncan's multiple range test).

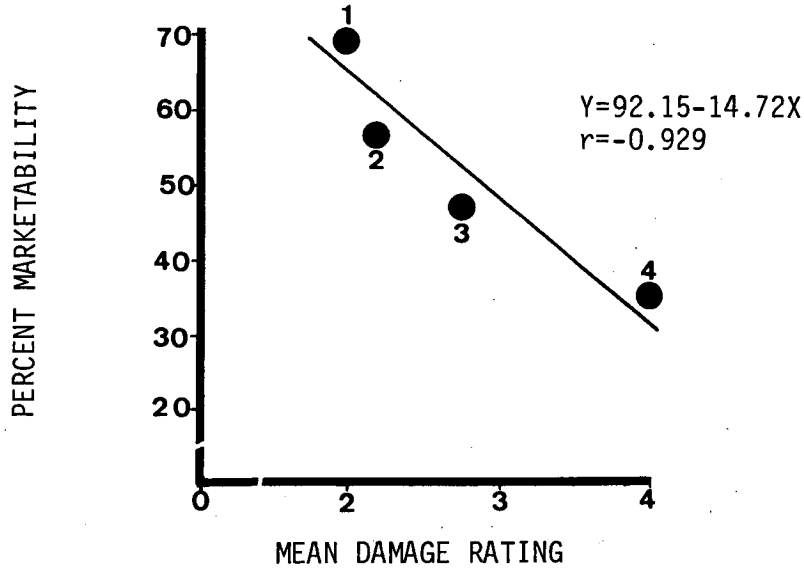



Fig. 7.8. Relationship between mean damage rating of cabbage plants at harvest and percent marketability.

1 Permethrin + pirimicarb plots
2 Maldison + pirimicarb plots
3 Dipel + pirimicarb plots
4 Control (untreated) plots.

In terms of the number of sprays, treatment 1 plots received 20 and 43 percent fewer sprays than the plots of treatment 2 and 3 respectively.

### 7.2.3 Experiment 3. Assessment of the effects of early and delayed applications of insecticides and identification of cabbage plant growth stages sensitive to pest infestation/injury

The importance of infestation at different growth stages of cabbage on ultimate yield and marketability is poorly understood. In this experiment, plants were categorized into 7 distinct phenological stages and two separate spray programmes were initiated each consisting

of seven treatments. In the first programme, all treatments received spray at the seedling stage. Next all treatments with the exception of one were sprayed at the post seedling stage and this process of deletion of sprays was continued through each stage to maturity. This programme resulted in a range of spray applications from 1 to 7. The second spray programme was the inverse of the former with treatments receiving progressively more applications with plant growth. These programmes are shown in Table 7.4.

Each plot contained 20 plants in 4x5 grids. The experimental design was of randomised complete blocks with 4 replicates. A combination of permethrin and pirimicarb insecticides (0.1 + 0.3 kg A.I/ha) was employed in this experiment. Plant growth stages were assessed with respect to their sensitivity to combined (multiple) or individual (partitioned) pest infestations using correlation-regression methods. Subsequently, an appreciation of the impact of pest infestation(s) during a particular growth stage on the marketable yield was obtained.

#### 7.2.3.1 Results

Population trends of CA, CWB eggs and larvae and DM larvae and pupae as affected by spray applications employed at different growth stages of cabbage crop are presented in Figs. 7.9-7.11.

The results show that higher gross yield, head weight (Table 7.5) and marketable yield (Fig. 7.12) were obtained from the treatments which received spray applications

Table 7.4 Spray application programme directed to suppress insect pests on different phenological stages of cabbage at S.J.F. College cabbage plots.

| Treatment No. | When applied | Insecticidal Pressure | Total sprays/ crop |
|---|---|---|---|
| | Programme I | | |
| 1 | Seedling-maturity | * * * * * * * | 7 |
| 2 | Post seedling-maturity | * * * * * * | 6 |
| 3 | Pre cupping-maturity | * * * * * | 5 |
| 4 | Cupping-maturity | * * * * | 4 |
| 5 | Post cupping-maturity | * * * | 3 |
| 6 | Pre heading-maturity | * * | 2 |
| 7 | Heading/maturity | * | 1 |
| | Programme II | | |
| 8 | Seedling | * | 1 |
| 9 | Seedling-post seedling | * * | 2 |
| 10 | Seedling-pre cupping | * * * | 3 |
| 11 | Seedling-cupping | * * * * | 4 |
| 12 | Seedling-post cupping | * * * * * | 5 |
| 13 | Seedling-pre heading | * * * * * * | 6 |
| 14 | Control (no application) | - | 0 |

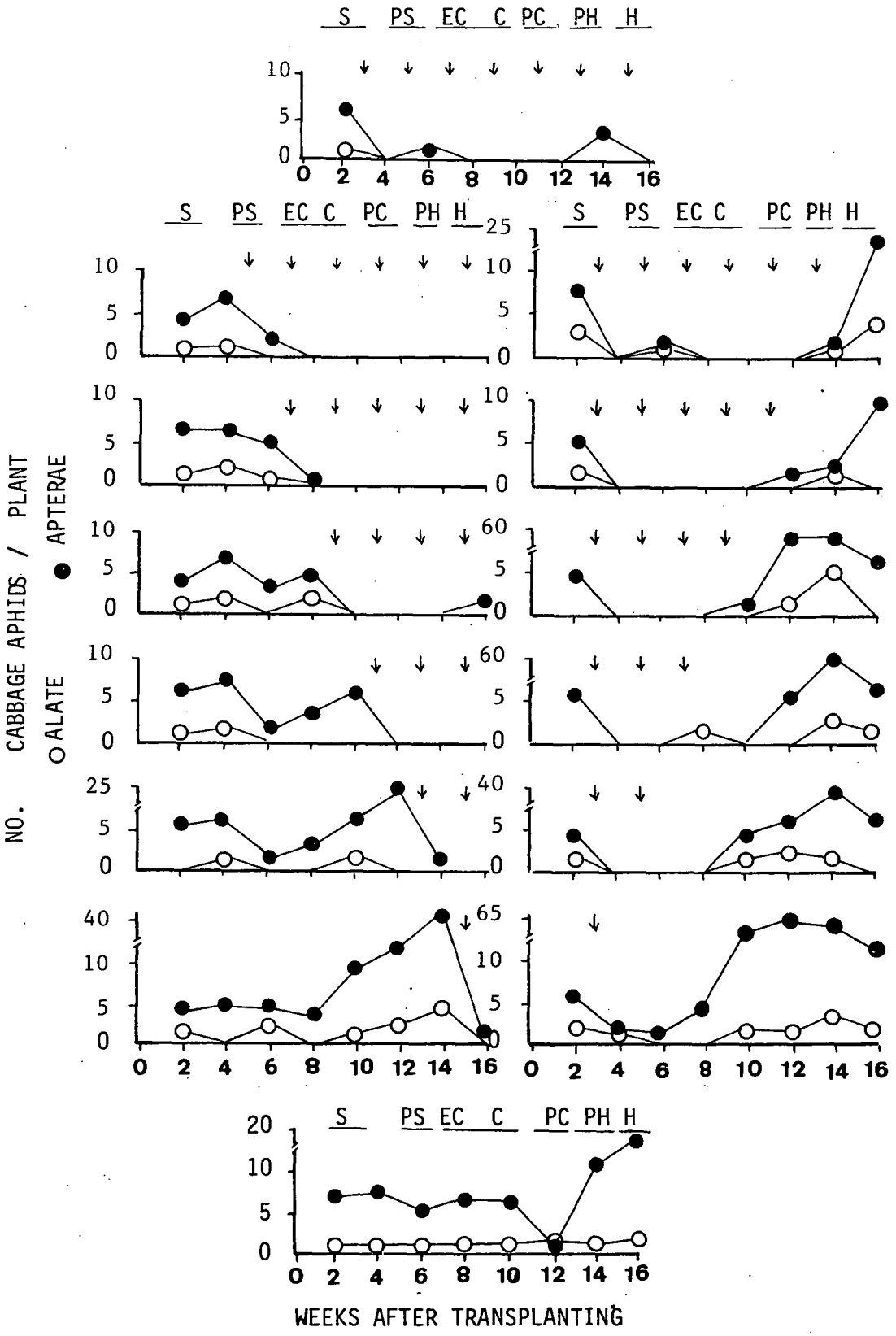



Fig. 7.9. Effect of timing of insecticidal sprays on the populations of cabbage aphid in cabbage plots at S.J.F. College (Nov.83-Mar.84). ↓ indicates insecticide spray. Growth stages of cabbage are denoted as : S...Seedling; PS...Post seedling; EC...Early cupping; C...Cupping; PC...Post cupping; PH...Pre heading; H...Heading.

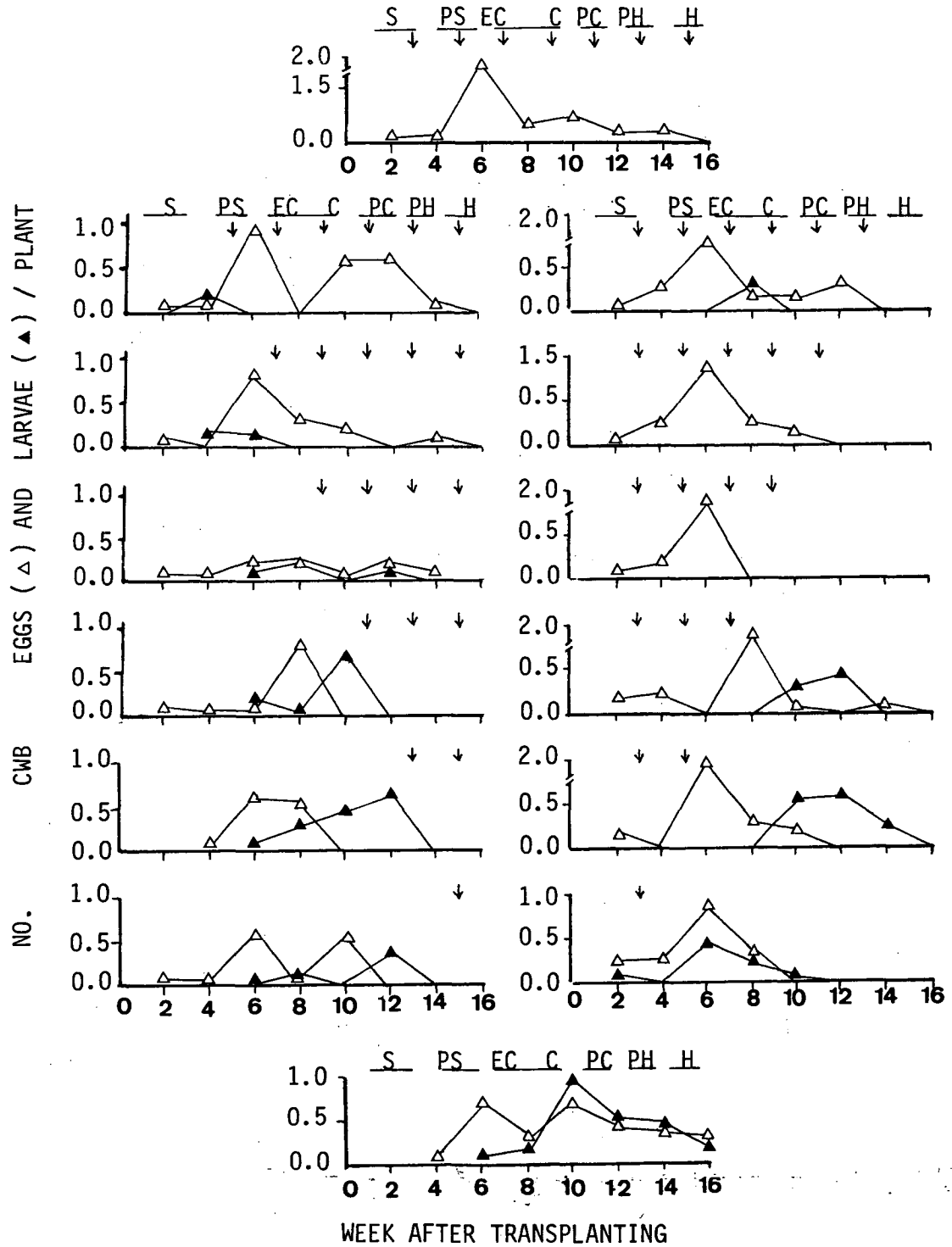



Fig. 7.10. Effect of timing of insecticidal sprays on the populations of CWB eggs and larvae in cabbage plots at S.J.F.College (Nov.83-Mar.84).↓ indicates spray application. Phenological stages of cabbage are denoted as :
S...Seedling ;
PS...Post seedling ;
EC...Early cupping ;
C...Cupping ;
PC...Post cupping ;
PH...Pre heading ;
H...Heading .

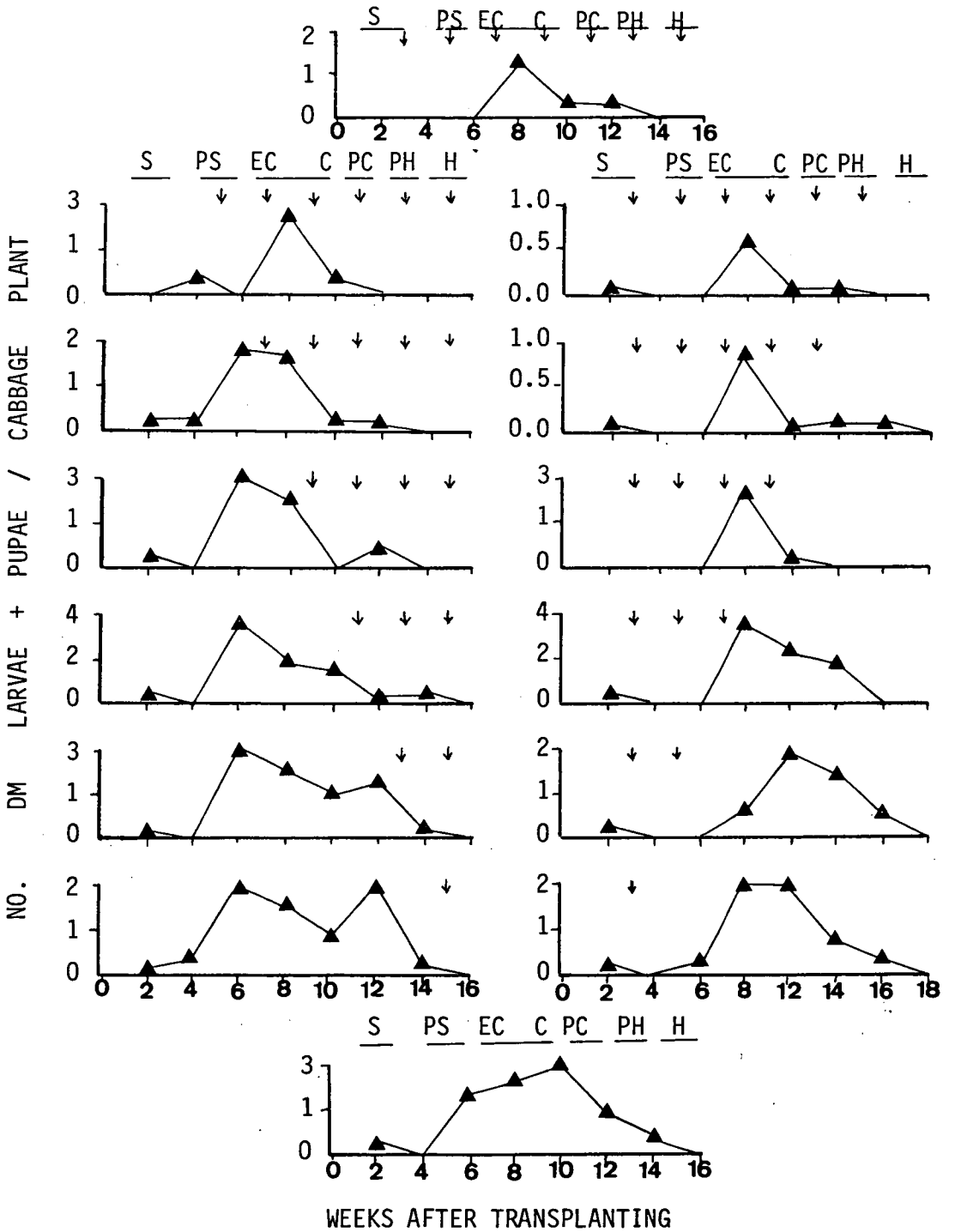



Fig. 7.11. Effect of timing of insecticidal sprays on the population of DM larvae and pupae in cabbage plots at S.J.F. College (Nov.83-Mar.84).↓ indicates spray application.Phenological stages of cabbage plant denoted as:
S...Seedling ;
PS...Post seedling ;
EC...Early cupping ;
C...Cupping ;
PC...Post cupping ;
PH...Pre heading ;
H...Heading.

Table 7.5 Timing of Spray application and differential performance of cabbage plants in plots at S.J.F. College (1983-84).

| Treatment No. | Timing of application | No. of application | Gross yield kg / plant | Mean head weight / plant (kg) | Stem diameter cm/plant | No. of nonhead leaves/ plant |
|---|---|---|---|---|---|---|
| | | | X | | | |
| 1 | Seedling-maturity | 7 | 3.35 abc | 1.63 abc | 2.24 abc | 9.20 |
| 2 | Postseedling - maturity | 6 | 3.12 abcd | 1.55 abc | 2.29 ab | 11.63 |
| 3 | Pre cupping - maturity | 5 | 2.76 bcdef | 1.30 bcd | 2.09 bcd | 11.17 |
| 4 | Cupping-maturity | 4 | 2.38 cdefg | 1.19 bcd | 1.99 cd | 11.13 |
| 5 | Post cupping - maturity | 3 | 2.15 defg | 1.13 bcde | 1.98 cd | 10.57 |
| 6 | Pre heading - maturity | 2 | 1.83 fg | 0.74 cde | 2.03 bcd | 11.93 |
| 7 | Heading or maturity | 1 | 1.69 g | 0.61 e | 2.04 bcd | 12.70 |
| 8 | Seedling | 1 | 2.09 efg | 0.71 de | 1.91 d | 11.77 |
| 9 | Seedling - post seedling | 2 | 2.92 abcde | 1.38 bcd | 2.31 ab | 11.67 |
| 10 | Seedling - pre cupping | 3 | 2.79 bcdef | 1.30 bcd | 2.25 abc | 10.00 |
| 11 | Seedling-cupping | 4 | 3.85 a | 2.07 a | 2.39 a | 9.47 |
| 12 | Seedling - post cupping | 5 | 3.54 ab | 1.85 ab | 2.32 ab | 10.63 |
| 13 | Seedling - pre heading | 6 | 3.59 ab | 1.84 ab | 2.28 ab | 11.73 |
| 14 | Control (untreated) | - | 1.86 fg | 0.72 de | 2.04 bcd | 11.77 N.S. |

X = Means followed by the same letters in each column are not significantly different ($P \geq 0.05$) when tested by Duncan's new multiple range test.

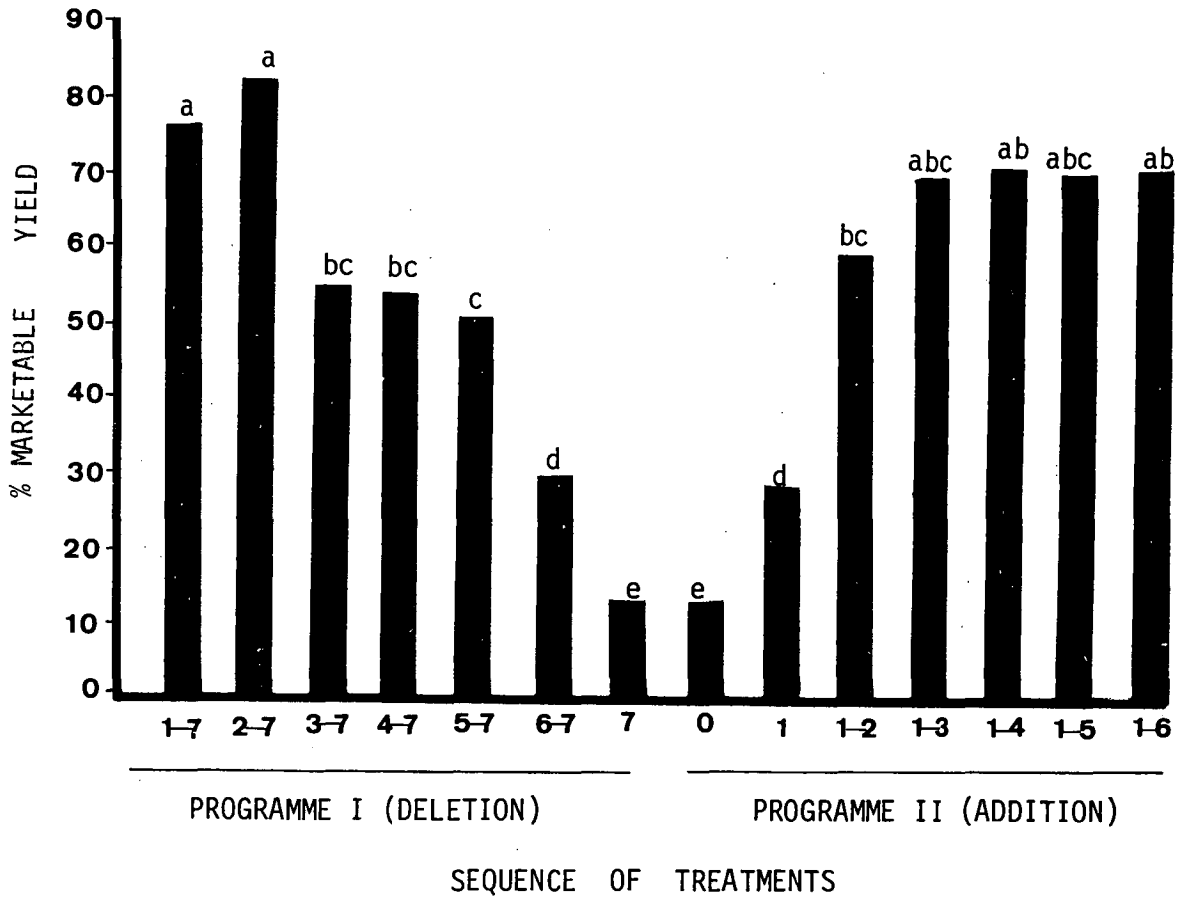



Fig. 7.12. Effect of timing of insecticidal sprays on sequential growth stages of cabbage plants at S.J.F. College plots (Nov.83-Mar 84). Numbers below the bars indicate spray timing at :

1 ... Seedling ;
2 ... Post seedling ;
3 ... Early cupping ;
4 ... Cupping ;
5 ... Post cupping ;
6 ... Pre heading and
7 ... Heading stages.

Any two treatments having the same letters, above the bars, are not significantly different ($p > 0.05$, Duncan's multiple range test).

either throughout the entire cropping period or at least from seedling to the cupping stages. The effect of the omission of sprays, in the first programme, was more pronounced than the addition of sprays in the second programme. Omission of sprays during post seedling (establishment), post cupping and pre heading stages caused significant reduction in the marketable yield. In the second programme, additional recruitment of sprays between seedling and post seedling stages provided a significant increase (P=0.05) in the marketable yield however, subsequent sprays during cupping to heading stages did not (Fig. 7.12).

The importance of early spray coverage during seedling and post seedling stages was reflected in both programmes. In the second programme, yields following 3 successive sprays from seedling to cupping stages were similar to those after 7 and 6 sprays in the first and second programmes, respectively.

Fig. 7.13 shows the trends in the predictability of the total marketable yield at harvest as a function of the total pest infestation at different phenological stages of cabbage plant. Infestations by CA, CWB and DM during post seedling-pre heading stages caused a significant decrease (P=0.05) in the proportion of marketable heads, however, this relationship was not found during the seedling and heading stages. The trends in the values of r and b express the predictability of the infestation marketability relationships and the degree of effect of infestations, respectively. Relatively, the infestation

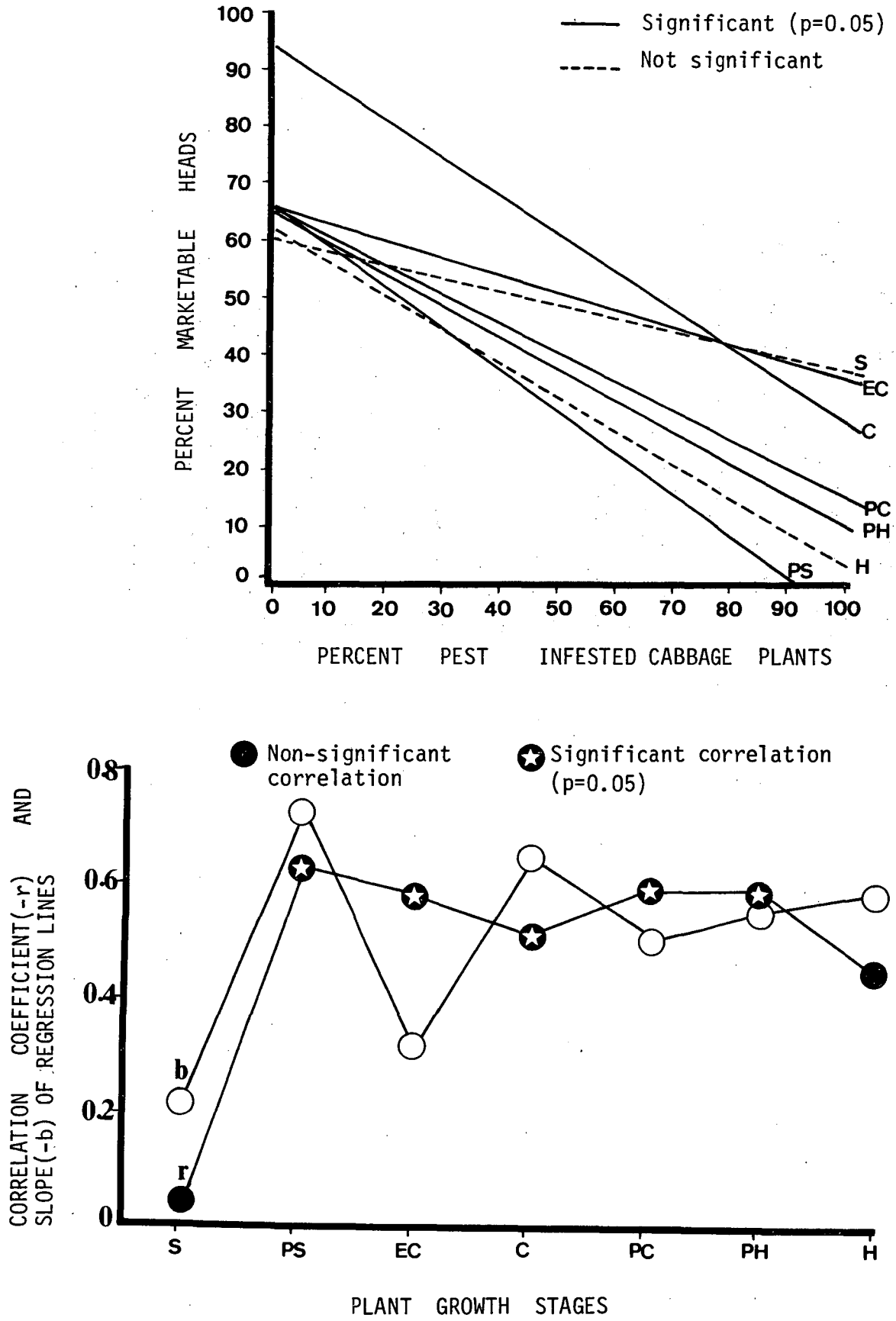



Fig. 7.13. Trends in the relationships between combined pest infestation at different growth stages of cabbage plants and marketability of cabbage heads at harvest. Plant growth stages abbreviated as: S...Seedling; PS...Post seedling; EC...Early cupping; C...Cupping; PC...Post cupping; PH... Pre heading; H...Heading.

marketability relationships were more predictable (high r values) during post seedling stage followed by cupping and pre heading stages.

Total pest infestations were partitioned into individual pest infestations of CA, CWB and DM and their relationships to the marketable yields are presented in Figs. 7.14, 7.15. Aphid infestations had the most serious impact ($P<0.01$) on the marketable yield during the cupping-post cupping period followed by the post seedling and pre heading stages ($P<0.05$). However, no such effect was found for seedling, early cupping and heading stages.

Defoliation/infestation by CWB larvae during early cupping-post cupping stages was significantly correlated with the decline in the marketable yield. However, a lower infestation during post seedling stage was positively, but non significantly, correlated with marketable yield. No significant effects of CWB feeding were found in other growth stages.

Infestation by DM larvae significantly reduced the marketable yield only during early cupping and pre heading stages. In common with CWB, a positive but non significant relationship between DM infestation and marketable yield was obtained in the post seedling stage. However, serious aphid infestation during this stage had a negative but significant correlation with the marketable yield.

Greater numbers of natural enemies were recorded on plants in the plots which received relatively fewer sprays, however similar trends were not found in sticky trap catches in different treatments (Table 7.6).

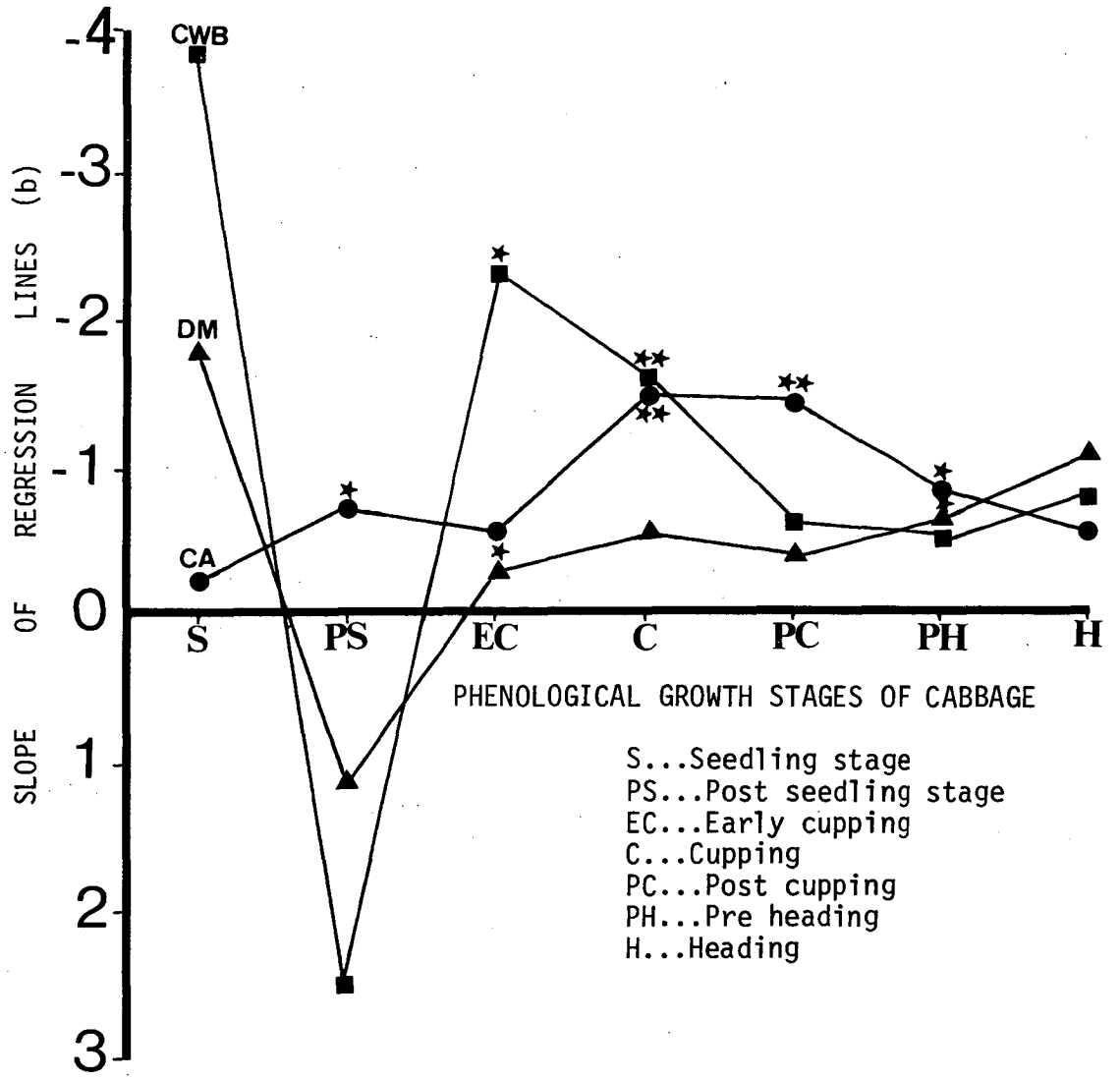



Fig. 7.14. The slope (b) of the regression lines generated from the relationships of individual (partitioned) infestation of cabbage aphid (CA), cabbage white butterfly (CWB) and diamondback moth (DM) at different growth stages of cabbage plants and marketability of cabbage heads at harvest.

★ $p<0.05$ ★★ $p<0.01$

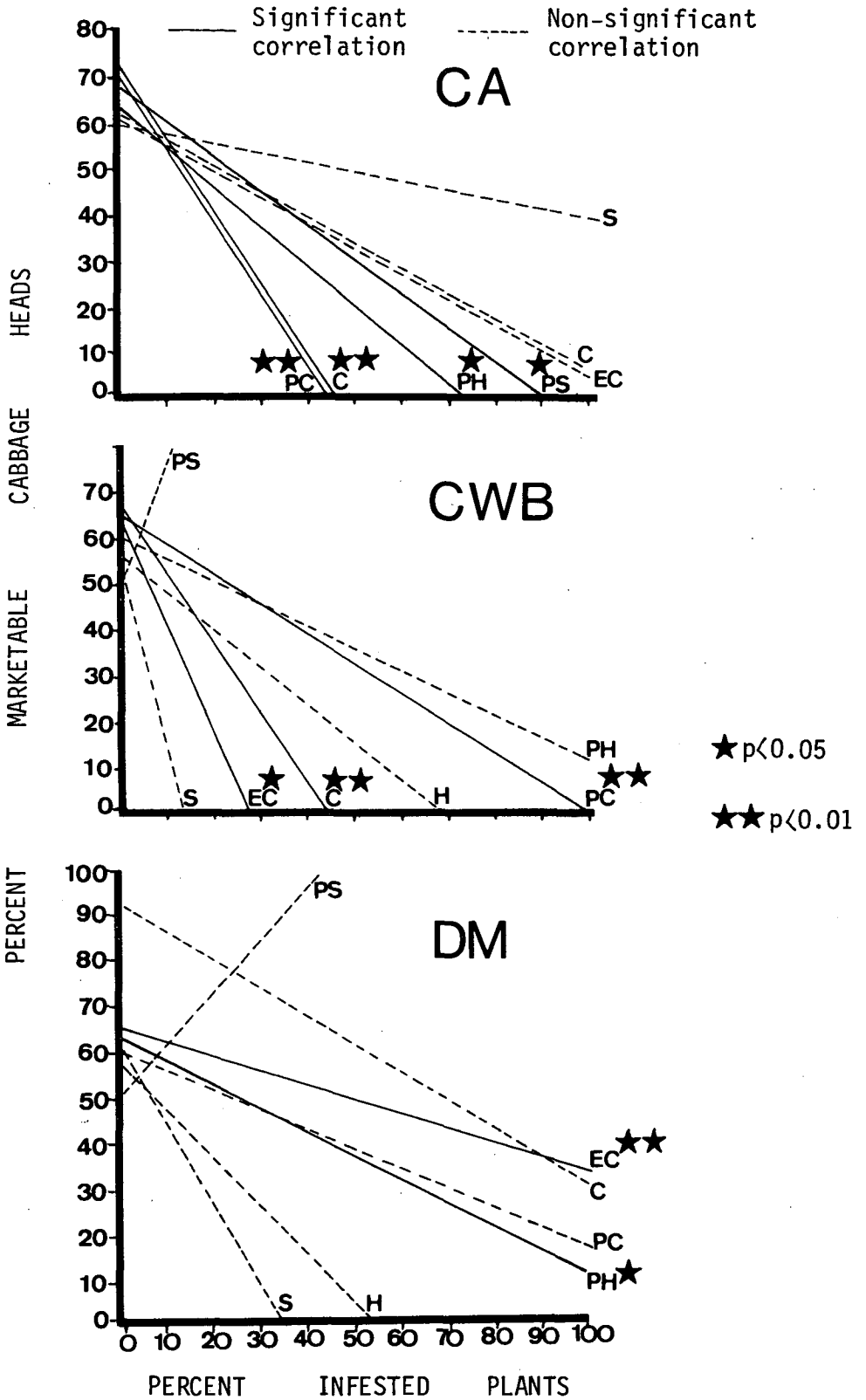



Fig. 7.15. Trends in the relationships between individual (partitioned) infestation of cabbage aphid (CA), cabbage white butterfly (CWB) and diamondback moth (DM) at different growth stages of cabbage plants and marketability of cabbage heads at harvest. Phenological growth stages of cabbage plant are denoted as: S...Seedling ; PS...Post seedling; EC...Early cupping; C...Cupping; PC... Post cupping; PH...Pre heading; H...Heading.

Table 7.6 Total number of key and potential parasitoids and predators recorded on cabbage plants (P) or caught in sticky traps (ST) in cabbage plots treated with phenologically varying insecticidal schedules at S.J.F. College (Nov.83 - Mar.84).

| Time of spray application | No. of sprays | | Taxon/Species[a] 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Seedling-Heading | 7 | P | 2 | 1 | 1 | - | - | - | - | - | - | - | - | - | - | 4 |
| | | ST | 2 | - | 2 | - | 4 | | | 2 | 2 | - | - | - | - | 12 |
| Post seedling-Heading | 6 | P | 4 | 1 | 1 | - | - | - | 1 | - | - | - | - | - | - | 7 |
| | | ST | - | 1 | 1 | - | 3 | | | 1 | - | - | - | - | - | 6 |
| Pre cupping-Heading | 5 | P | 7 | - | - | - | - | - | - | - | - | - | - | - | | 7 |
| | | ST | 1 | - | - | - | 1 | | | 3 | - | - | - | - | - | 5 |
| Cupping-Heading | 4 | P | 12 | - | - | - | - | - | 2 | - | - | 1 | - | - | - | 15 |
| | | ST | 2 | - | - | 1 | - | | | 4 | 2 | 2 | - | - | - | 11 |
| Post cupping-Heading | 3 | P | 4 | - | - | - | - | 1 | - | - | - | - | 1 | 1 | - | 7 |
| | | ST | 4 | - | 1 | - | 3 | | | 1 | - | 3 | - | - | - | 12 |
| Pre heading-Heading | 2 | P | 13 | - | 1 | - | 1 | 5 | - | - | - | 2 | 1 | - | - | 23 |
| | | ST | 8 | - | 4 | - | 3 | | | 6 | 7 | 5 | 1 | - | - | 35 |
| Heading | 1 | P | 12 | 2 | 2 | - | 1 | 8 | 3 | - | - | - | 2 | - | - | 30 |
| | | ST | 4 | - | 5 | - | - | | | 2 | 2 | 1 | - | - | 2 | 16 |
| Seedling-Pre heading | 6 | P | 1 | - | - | - | - | - | - | - | - | - | - | - | - | 1 |
| | | ST | 1 | - | 1 | - | - | | | - | - | - | - | - | 1 | 3 |
| Seedling-Post cupping | 5 | P | 1 | - | - | - | - | 2 | - | - | - | - | - | - | - | 3 |
| | | ST | - | - | 2 | 4 | 1 | | | - | - | - | - | - | - | 7 |
| Seedling-Cupping | 4 | P | 33 | 1 | - | - | 1 | 3 | - | - | - | 1 | - | - | - | 39 |
| | | ST | 13 | - | - | 2 | - | | | 2 | - | - | - | - | - | 17 |
| Seedling-Pre cupping | 3 | P | 9 | - | 1 | - | - | - | 4 | 2 | - | 3 | - | - | - | 19 |
| | | ST | 12 | - | 5 | - | 4 | | | 4 | 2 | 6 | 1 | - | - | 34 |
| Seedling-Post seedling | 2 | P | 6 | 2 | 2 | - | 2 | 2 | 2 | - | - | 4 | 3 | - | - | 23 |
| | | ST | 4 | - | 9 | - | - | | | 3 | - | 3 | - | - | - | 19 |
| Seedling | 1 | P | 16 | - | 2 | - | - | 4 | 2 | - | - | 4 | 2 | - | - | 30 |
| | | ST | 9 | - | 3 | | - | | | - | 2 | 4 | - | - | - | 18 |
| Control (untreated) | 0 | P | 15 | 3 | 4 | - | 4 | 12 | 7 | - | - | 3 | - | - | - | 48 |
| | | ST | 26 | - | 13 | 6 | 6 | | | - | 2 | 7 | - | - | - | 60 |

[a] = Species denoted as :
1=Diaeretiella rapae (Aphid parasitoid); 2=Alloxysta brassicae (Aphid hyperparasitoid); 3=Micromus tasmaniae ( Brown lace wing); 4=Coccinella repanda(Lady bird beetle); 5=Melangyna viridiceps (Syrphid fly); 6=Ants; 7=Spider; 8=Apanteles glomeratus (CWB larval parasitoid); 9=Pteromalus puparum (CWB pupal parasitoid); 10=Diadegma rapi (DM larval parasitoid); 11=Thyraeella collaris (DM pupal parasitoid). No. of plants and sticky traps examined were 27 and 3 / sampling respectively.

Overall impact of combined and partitioned (individual) pest infestation on different growth stages of cabbage plant and the marketable yields is summarized in Table 7.7.

### 7.2.4 Experiment 4. Comparison of spraying strategies based on action thresholds and plant development

Traditionally spray decisions have been determined by the prevalence and density of the pest population. In the previous experiments, it was shown that the effect of pest infestation/injury and the effectiveness of spray applications vary according to the growth stage of cabbage plant. In this experiment plant development and two insect pest action thresholds based on chemicals alone (CAT) or integrated with Dipel (IAT) were used as criteria for spray application decisions and subsequently their relative effectiveness was compared. Details of treatments are shown in Table 7.8.

#### 7.2.4.1 Results

The seasonal trends in the numbers of insect pests in different treatments are presented in Fig. 7.16. Intensive, phenological and CAT sprays provided a marked suppression of all pests, however IAT sprays were less effective compared with other treatments. Only 3 CAT sprays were required to suppress pest populations below critical levels as compared to the 7 intensive, 6 phenological and 5 IAT spray applications.

Table 7.7 Relationships between combined and individual pest infestation levels at different growth stages of cabbage plants and marketable yield. r = Coefficient of determination of pest infestation and marketable yield (%), b = Slope of the regression line.

| Plant growth stage | r | | | | b | | | |
|---|---|---|---|---|---|---|---|---|
| | CA+CWB+DM | CA | CWB | DM | CA+CWB+DM | CA | CWB | DM |
| Seedling | 0.002 | 0.002 | 0.100 | 0.090 | -0.214 | -0.214 | -3.840 | -1.748 |
| | * | * | | | | | | |
| Post seedling | 0.393 | 0.400 | 0.084 | 0.136 | -0.733 | -0.741 | 2.58 | 1.147 |
| | * | | * | * | | | | |
| Pre cupping | 0.342 | 0.112 | 0.377 | 0.430 | -0.312 | -0.565 | -2.33 | -0.328 |
| | * | ** | ** | | | | | |
| Cupping | 0.253 | 0.651 | 0.458 | 0.219 | -0.655 | -1.511 | -1.529 | -0.609 |
| | * | ** | ** | | | | | |
| Post cupping | 0.348 | 0.603 | 0.449 | 0.181 | -0.505 | -1.465 | -0.683 | -0.426 |
| | * | * | | * | | | | |
| Pre heading | 0.338 | 0.246 | 0.214 | 0.299 | -0.553 | -0.838 | -0.501 | -0.514 |
| Heading | 0.206 | 0.176 | 0.115 | 0.127 | -0.591 | -0.550 | -0.817 | -1.035 |

CA = cabbage aphid ; CWB = cabbage white butterfly ;
DM = diamond-back moth infestation
* = $P<0.05$ ** = $P<0.01$

Table 7.8 Spray programme for the comparison of different strategies employed against cabbage pests at S.J.F. College cabbage plots (1984-85).

| Treatment no. | Criterion | Insecticides | Rate of application kg. A.I/ha |
|---|---|---|---|
| I | Intensive | Permethrin E.C. + pirimicarb W.P. | 0.1 + 0.3 |
| II | Phenological | Permethrin E.C. + pirimicarb W.P. | 0.1 + 0.3 |
| III | Chemical action threshold | Permethrin E.C. and/or pirimicarb W.P. | 0.1 + 0.3 |
| IV | Integrated action threshold | Dipel W.P and/or pirimicarb W.P. | 0.6 + 0.3 |
| V | Untreated (Control) | - | - |

X=Intensive=Biweekly sprays regardless of pest presence.

Phenological=Each of 6 growth stages of cabbage received one spray.

Action threshold = Spray was applied when CWB/DM larvae > 0.2/plant and /or cabbage aphids > 5/plant In treatment 3 and 4 pirimicarb was included with permethrin and Dipel only when cabbage aphid densities>5 aphids/plant.

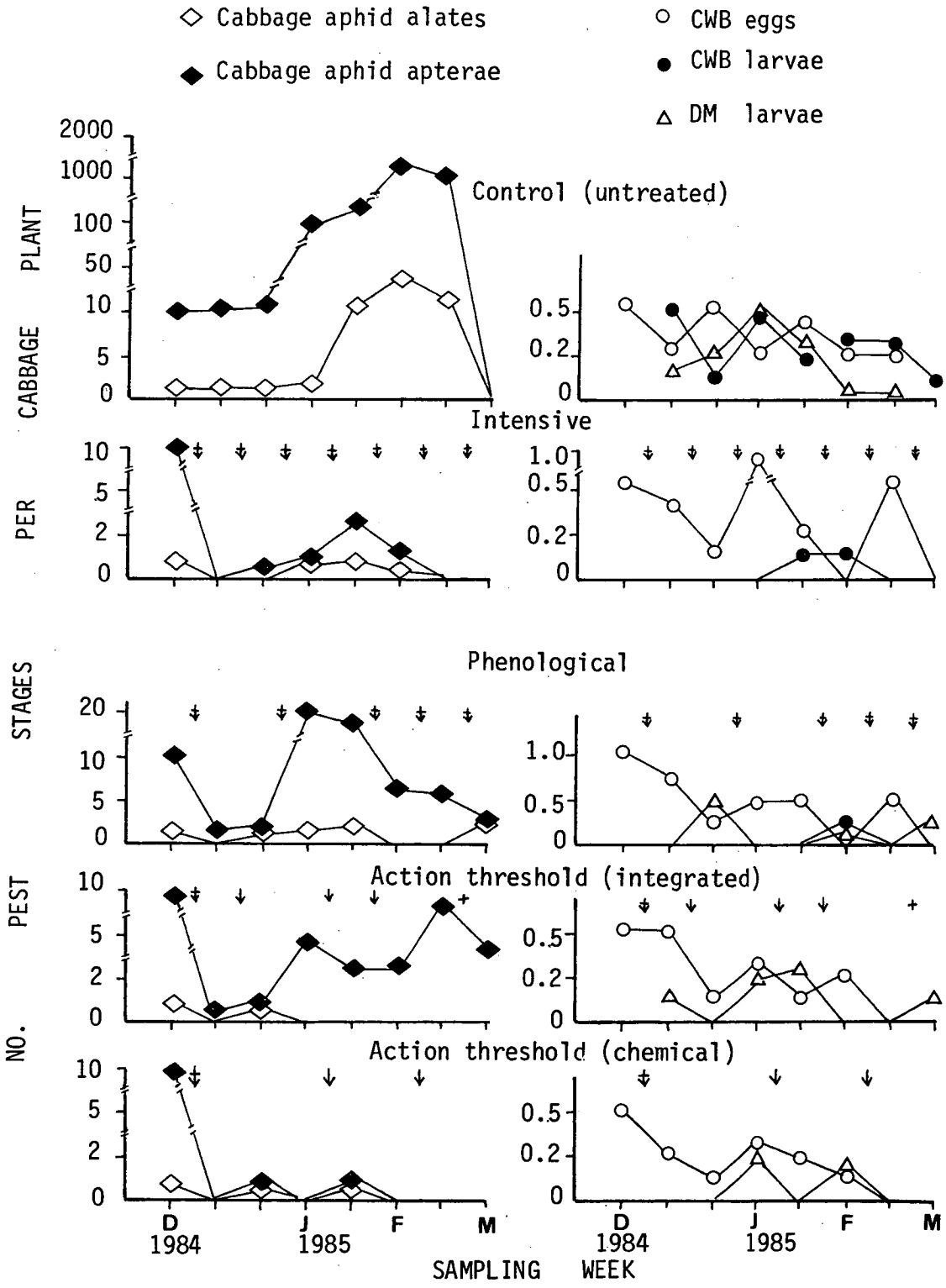



Fig. 7.16. Populations of cabbage aphid, cabbage white butterfly (CWB) eggs and larvae and diamondback moth (DM) larvae in plots of cabbage treated with chemical and/or microbial insecticides with different criteria applied in treatment decisions. ↡ indicates spray application against aphids and larvae. + and ↓ indicate spray application against aphids and larvae respectively.

Numbers of natural enemies were greater in the untreated plots followed by CAT>IAT>phenological>intensive spray plots (Fig. 7.17).

Mean damage rating and marketable heads (%) in intensive, phenological and CAT treatments were not significantly different (P=0.05) from each other (Table 7.9) but the mean damage ratings were strongly correlated($P<0.005$, $r=-0.997$) with percent marketable heads (Fig. 7.18). The spraying strategy based on action thresholds and including permethrin and/or pirimicarb was highly cost effective in terms of spray frequency and marketable yield.

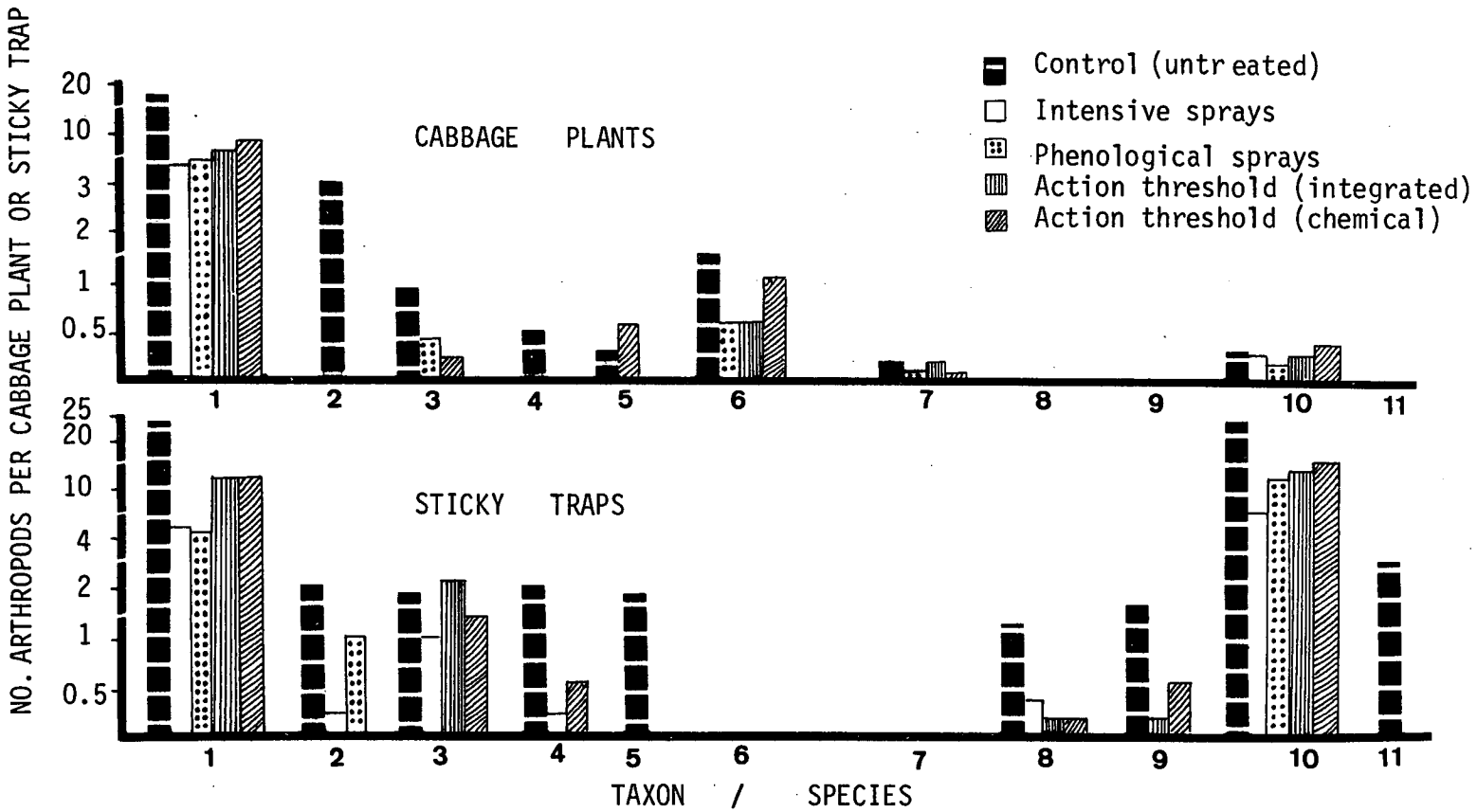



Fig. 7.17. Total number of key parasitoids and potential predators recorded on cabbage plants or caught in sticky traps in cabbage plots treated with different schedules of chemical and/or microbial spray applications (S.J.F. College ,Dec.84-Mar.85).Taxon/species denoted as: 1...Diaeretiella rapae ; 2...Alloxysta brassicae ; 3...Syrphids ; 4...Coccinellids ; 5...Brown lacewing ; 6...Ants ; 7...Spiders ; 8...CWB larval parasitoid (Apanteles glomeratus); 9...CWB pupal parasitoid (Pteromalus puparum) ; 10...DM larval parasitoid (Diadegma rapi) ; 11...DM larval parasitoid (Apanteles plutellae).

Table 7.9 Efficacy of insecticidal spray schedules against cabbage pests, damage rating and yield in different treatments at S.J.F. College plots (1984-85).

| No. | Treatment & rate of application kg A.I./ha | No. spray applications | Mean damage rating X | Yield: Gross yield kg / plant | Yield: Mean head weight kg | Yield: Marketable heads % | Cost of insecticides |
|---|---|---|---|---|---|---|---|
| | | | Y | | | | |
| 1 | Permethrin + pirimicarb 0.1 + 0.3 | 7 | 1.33 d | 1.94 | 1.40 | 87.4a | 145.6 |
| 2 | Permethrin + pirimicarb 0.1 + 0.3 | 6 | 2.37 bc | 1.47 | 1.11 | 66.4bc | 124.82 |
| 3 | Dipel + pirimicarb 1.0 + 0.3 | 1 | 3.00 ab | 1.64 | 1.05 | 54.0cd | 31.37 |
| | Dipel 1.0 | 3 | | | | | 70.50 |
| | Pirimicarb 0.3 | 1 | | | | | 7.83 |
| | | | | | | | 109.70 |
| 4 | Permethrin + pirimicarb 0.1 + 0.3 | 1 | 1.50 bcd | 2.08 | 1.50 | 83.3ab | 20.8 |
| | Permethrin 0.10 | 2 | | | | | 25.95 |
| | | | | | | | 46.75 |
| 5 | Control | - | 3.80 a | 1.52 N.S. | 1.09 N.S. | 33.3d | - |

X = Based on 1-6 damage scoring system of Greene et al. (1979).

Y = Means followed by the same letters in each column are not significantly different (P>0.05) when tested by Duncan's new multiple range test.
N.S. = Not significantly different.

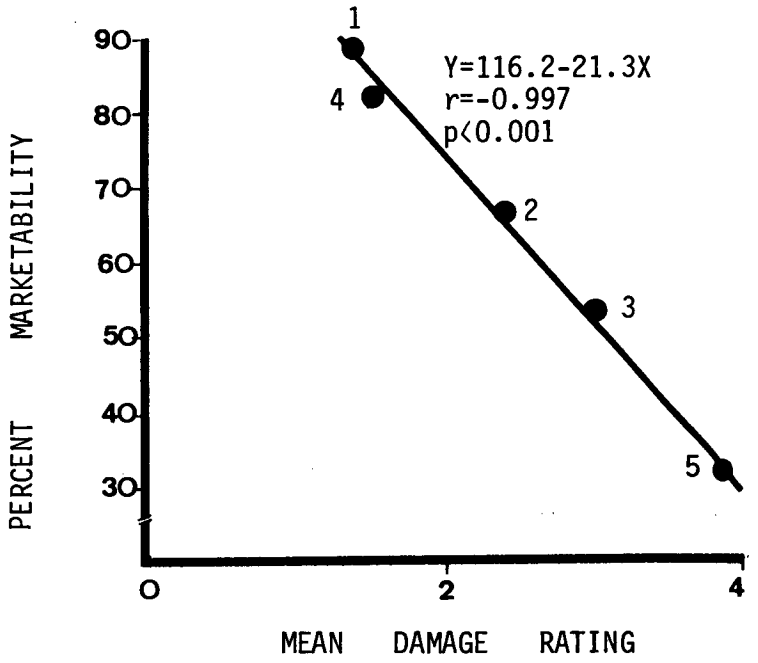



Fig.7.18. Relationship between mean damage rating of cabbage plants at harvest and percent marketability.Numbers on the regression line represent different treatments as:
1...Intensive (permethrin + pirimicarb)
2...Phenological (permethrin + pirimicarb)
3...Action threshold - integrated (Dipel + pirimicarb)
4...Action threshold - chemical (permethrin + pirimicarb)
5...Control (untreated)

## 7.3 Discussion

This investigation indicates that reliable control of cabbage pests could be obtained through regular inspection of the crop, use of action thresholds, accurate timing of control measures and appropriate selection of the pesticides. Basically, the information on the pest densities led to precise decision making to initiate pest control measures. Norton and Conway (1976) have also emphasized that improved pest control involved the development of the better decision rules.

Ironically, commercial cabbage growers rely on intensive use of insecticides without regard to the actual pest density in the field (cf. Chapter 6). Intensive insecticide usage has poor economic justification as it eliminated natural enemies and had deleterious effects on plant productivity. Johnson et al. (1983) have reported a marked reduction in the yield of lettuce treated with increased number of methyl parathion applications during the growing season.

It is noteworthy that permethrin, a pyrethroid; and maldison, an organophosphate, were effective against both lepidopterans. Continuous and persistent usage of certain organophosphate insecticides have already led to the development of resistance in DM (Suddreddin and Kok, 1978; Sun et al., 1978). This fact is particularly pertinent in Tasmania where brassica vegetables are grown almost all the year round and the growers and pest control consultants employ the same toxicants each season. In these circumstances, regular pest monitoring is of crucial

importance and the crop inspection costs may well be recovered by reductions in unnecessary pesticide applications. Simonet and Morisak (1982) considered that a reduction of spray application by the use of more effective materials with proper timing should be a preferable approach to realize a profitable production. Likewise, a 54% increase in insecticidal effectiveness associated with a 49% reduction in the insecticidal usage was attributed to the use of field monitoring information and action thresholds by Andaloro et al. (1983).

The simple thresholds, as utilized in this study, could be rapidly estimated during normal crop inspection and may be used by the grower. In contrast, Adkisson (1973) considered that the spray programmes based upon regular crop inspection and pest thresholds have a low rate of adoption due to a lack of grower's confidence in estimating thresholds. This aspect becomes more difficult when risk aversive growers are interested in the profit maximization through heavy loads of chemical sprays to keep the growing plant or the marketable product free of any infestation.

The relatively poor performance of Dipel sprays against DM infestation is attributed to the lack of contact between the sprayed material and the larvae which hide within the foliage. This contrasts to CWB larvae which were always exposed to bacterial spores. Workman et al. (1980) reported better control of DM with permethrin compared with B.t. applied alone or in combination with methomyl and methamidophos. Despite the failure of Dipel

to provide a reliable control of DM in this investigation, integration of biological and chemical control tactics, as Hull et al. (1985) have suggested may be the only logical strategy in a multi-pest system where at least one pest is a candidate for biological control. Unfortunately, a shortcoming in the adoption of such integrated methods is the low pest tolerance by both the producer and the consumer and as a consequence the producers find calender/insurance spraying an easier concept to utilize than more complex but environmentally and economically sounder integrated programme (Wearing, 1982).

The results also show that the effect of pest injury varies according to plant growth stage (see also Bardner and Fletcher, 1974). So another practical strategy to reduce pesticide usage is to time the spray applications according to the differential sensitivity of growth stages of cabbage crop to pest damage. Aphid infestations during the post seedling stage often resulted in severe stunting from which the plants never recovered causing serious declines in the productivity of the infested plants. However, losses in the marketable yield due to aphid infestation were mainly of a cosmetic nature during the later growth stages. Similarly, DM infestation during the seedling stage caused serious damage to primordial leaves which ultimately resulted in either failure to produce heads or cause multiple heading which was of no economic value. Later, in the season DM infestation caused serious cosmetic damage during pre heading-heading stages.

Although the growth rate of cabbage plants depends on

their photosynthesizing area (e.g. Samson and Geier, 1983) mild defoliation by CWB and DM larvae were rapidly compensated (see also Harris, 1974) during the post seedling stage and CWB defoliation during cupping stages either caused changes in the plant development or the head formation. Although subsequent damage did not affect the head *per se* it did affect the quality via cosmetic effects.

Overall protection from the invasion of 3 pests is particularly required from the seedling to post cupping stages to enhance the head formation process. Any infestation on the subsequent growth stages affects the cosmetic value by harming the appearance of the marketable product. This was exhibited by aphid infestations which caused significant declines in the marketable yield during pre heading stage. However the effect of any infestation during heading stage may be avoided by the removal of a few leaves from the marketable product. In contrast, Chalfant *et al*. (1979) reported that lepidopteran damage caused before the head leaves were formed had less effect on marketability of the crop than had later damage.

The present investigation shows that omission of sprays during post seedling, post cupping and pre heading stages significantly reduced the marketable yield, however, when the earlier vegetative stages were protected, the further addition of sprays in the later heading stages did not increase the marketable yield. Furthermore, the impact of either single or multiple insect pest infestation during different growth stages on

the productivity of cabbage plant was quantified in terms of marketable yield assessed at the time of harvest. This may have been oversimplified as the plant yield is most often governed by multiple factors such as growth or development pattern of plant, pest-host plant interaction, pest density and environmental factors (Bardner and Fletcher, 1974). However, considering the pest infestation levels in the field recorded on different growth stages of cabbage plant, relationships were established with the final marketable yield.

Combined pest infestations during post seedling, early cupping - post cupping and pre heading stages caused significant reductions in the marketable yields. However, pest infestations during seedling or heading stages did not cause any significant reduction in yield. This was due to the fact that infested outer leaves during seedling stage mostly drop off and may not contribute to the final yield whereas infestation during heading stage may be avoided by removing the infested leaves from the marketable portion. Individually, aphid infestation showed similar effects except that infestations during cupping and post cupping stages were relatively more damaging due to their sheltered establishment in the foliage and were often protected from control measures.

The sensitivity of cupping stages to CWB larval feeding was reflected in the undersized or malformed heads at harvest, however, infestation in other stages and their impact on the yield is attributed either to compensation or tolerance on the part of the cabbage plant. The same

phenomenon is applicable to DM infestation though its impact was more serious during early cupping than preheading stage.

A minimum of 3 growth stages of cabbage plant should be protected to obtain optimum productivity. i.e. post seedling, post cupping and pre heading. Spray programmes based upon either action thresholds or omission-sprays support this inference. This finding may be of considereable benefit for economic and environmental reasons. Omission of spray during seedling stage may help natural enemies to establish whereas a non-spray period during the heading stage may minimize any residual toxicant in the marketable product.

The preference of less damaged plants by the CWB females for oviposition corroborates previous finding (Lundgren, 1975; Renwick and Radke, 1980; Sears et al., 1983) that the females rejected damaged or infested plants for oviposition.

The damage rating system employed in this study proved to be an efficient and reliable method. In contrast, Kirby and Slosser (1984) did not find any consistency between the damage rating and marketable yield. They, however, concluded that this lack of agreement was due to the fact that both characteristics were expressed as means and did not recognize variations.

## 7.4 Conclusions

The following determinations are made from this investigation :

(1) Use of traditional commercial spray programmes has little justification for economic and environmental reasons.

(2) Reliable pest control is feasible through regular crop inspection, use of action thresholds and proper selection and timing of insecticidal applications.

(3) Cabbage plant has two main growth phases namely ;

   (a) vegetative, which extends from seedling to cupping stages and

   (b) heading, which lasts from the central bud formation to the development of marketable head.

(4) Cabbage plants require protection from pest invasion during the vegetative phase to enhance yield factors and in post vegetative (heading) phase for cosmetic reasons.

(5) Pest invasions have differential effects on the plant growth, development and the final yield. Likewise, plant growth stages have a differential sensitivity to pest attacks.

(6) The unilateral impact of pest infestation on the plant economy may be quantified by the relationship/interaction between pest infestation levels and the performance of the plant reflected in the final yield.

# CHAPTER 8

# EVALUATION OF MICROBIAL AGENTS FOR INSECT PEST SUPPRESSION ON CABBAGE

## 8.1 Introduction

In Australia , current insect pest control strategies in brassica vegetable crops are primarily centered on the application of chemical insecticides. However, because of the growing economic and environmental limitations and restraints imposed by the continuous usage of chemical insecticides (cf. Chapter 2), ways have to be devised to:

(a) reduce routine chemical treatments;

(b) develop and utilize alternative, safe and effective means of pest suppression and

(c) integrate their selective use and optimize their benefits.

Of late, there has been a growing emphasis on the development and use of microbial agents as insecticides. In this context, although the potential of entomopathogenic nematodes and fungi for the suppression of economic insect pests has held great interest (e.g. Gaugler, 1981; Hall and Papierok, 1982) their application against cabbage pests has not been considered experimentally in Australia. The feasibility of using these microbial agents for field control of cabbage pests remains to be demonstrated.

This investigation was undertaken to evaluate whether:

(a) steinernematid nematodes could be used to

suppress lepidopteran pests and what method enhance their efficacy and survival on the cabbage plants and

(b) if the entomopathogenic fungus, Verticillium lecanii, could provide a reliable suppression of cabbage aphid population in comparison with a chemical aphicide.

## 8.2 Materials and Methods

### 8.2.1 Evaluation of entomopathogenic nematodes against lepidopterans

#### 8.2.1.1 Source of nematodes

All nematodes were obtained from Dr. R.A. Bedding, Division of Entomology CSIRO Laboratories Hobart, where nematodes were reared in vitro by a method used for mass production of nematodes (Bedding, 1981). Nematodes were isolated from the rearing medium and suspended in water. Aqueous suspensions were continuously aerated to prevent nematode sedimentation and mortality till their application. Two strains of infective nematodes namely Steinernema feltiae (Agriotos) and S. bibionis (T335) were used in this investigation.

#### 8.2.1.2 Laboratory tests

Larvae (3rd-5th instars) and pupae of CWB and DM, collected from cabbage plants in the insect rearing cages at the Faculty of Agricultural Science, were exposed per replicate to 2000 infective nemas in aqueous suspension. Larvae or pupae were placed on a Whatman no. 1 filter

paper (9 cm) in a sterile petri dish (100×15mm) and 2 ml of nematode suspension was added with micropipette. Three DM larvae or pupae and 2-3 CWB larvae (depending upon their instar) or pupae were used in each petri dish. Distilled water was pipetted onto other dishes as controls.

For comparisons CWB and DM larvae were placed on cut circles of cabbage leaf in the petri dishes. Leaf circles were sprayed with Dipel, B.thuringiensis var alesti) by hand-held plastic bottle sprayer. Each leaf circle received ca. 8640 i.u. (2 mg) of Dipel in 2 ml of water. The dishes were stored at 20±2 °C for 48 hours or more. Infection of larvae or pupae was determined from characteristic discolouration and flaccid appearance and confirmed later by dissection of morbid individuals. Non-infected individuals were reared on fresh leaves of cabbage for their development into the next stage.

### 8.2.1.3 Field trials to determine parasitism, dispersal and survival of nematodes

#### 8.2.1.3.1 Trial 1. Kingston, 1983

For practical utilization it was very important to know an effective method of application which would enhance both parasitism and survival of nematodes under field conditions.

In this trial both strains of nematodes were thinly pasted on spongy polyfoam cubes (2×1.5 cm per cube) placed in culture dishes after their separation from the rearing media (Bedding, 1981). Nematodes were left for 30 minutes

to penetrate the cubes resulting in ca. $0.5 \times 10^6$ infective nemas per cube and cubes were placed between foliage of DM infested cabbage plants (n=20 per treatment) at pre heading stage in the commercial grower's field at Kingston. One cube was placed in each plant. The temperature and relative humidity during this trial as recorded from the nearest meteorological station varied from 25 to 10°C and 82 to 60% respectively. Plants were watered by overhead sprinkler by the grower 5 days after nematode application. Plants (n=10 per treatment) were carefully harvested after 2 and 10 days and brought back to laboratory along with sponges. All insect stages on the plants were isolated, examined for infection or reared for further development.

Sponges were immersed in 500 ml of water in a beaker to release the nemas. Subsequently, live and dead nematodes were counted in glass dishes under a binocular. A nematode was considered alive if it showed active signs of movement or wriggling.

Nematode survival or dispersal was determined by washing all wrapper leaves and 2 pairs of heading leaves with tap water. The washings were then examined for living nematodes.

Percentage data were transformed to arcsine values and subjected to ANOVA and treatment means of infection/mortality of pest larvae and/or survival of nemas compared by Duncan's multiple range test in this and the following trials.

8.2.1.3.2 Trial 2. S.J.F. College, 1983

Experimental plots (2×2m per plot) of Ballhead cabbage were established at S.J.F. College in the first week of February, 1983. Seedlings were sprayed each week with nutrient solution Aquasol® for rapid establishment and growth and sprayed once with pirimicarb to suppress any aphid infestation. Four weeks later, at pre cupping stage, cabbage plants were artificially infested with DM and CWB larvae (3rd-4th instars) collected from glasshouse rearing cages. Each plant was infested with at least 2 larvae of DM and CWB. There were 20 plants per treatment. Infective nemas, S. feltiae and S. bibionis, suspended in water containing a wetting agent Arlaton (ICI Americas Inc., Wilmington, Del.) 0.1% v/v were sprayed on each plant ($0.5\times10^{6}$/plant) with a Solo back-pack sprayer through a single fan nozzle at a pressure of 24-28 $g/mm^{-2}$ (Miller and Bedding, 1982, Fig. 8.1). Plants were watered with sprinklers according to need. Water sprays were used as controls. A similar spraying technique was used in the following trials. Parasitism and survival of nematodes were assessed 3 and 10 days after the date of treatment. Ten plants were harvested on each sampling and brought back to the laboratory. Assessment of parasitism and survival was conducted as in Trial 1.

8.2.1.3.3 Trial 3. CSIRO Experimental Station, 1983-84

Following the observation that a marked proportion of nematodes could survive on the cabbage foliage at least

A


Fig. 8.1. Nematodes spray equipment (A) and material retention on cabbage foliage (B).

B

for 2 days after their application, this field trial was conducted to assess the efficacy of both strains of nematodes applied in aqueous suspensions containing a synthetic evaporation retardent and antidesiccants.

Cabbage plots (2×1 m/plot) were established at the CSIRO Forestry Experimental Station located near Hobart airport. Plants were kept aphid free by pirimicarb treatments when required. Nematodes were suspended in water added with Xanthin Gum® (Kelco Company Ltd., a sample of Kelzan S®, 0.25% w/v); Folicote® (Sunoco Company, Ramsay and Treganowan Ltd., Melbourne, 1% v/v) and Arlatone™ (0.1%). Folicote, a liquid evaporation retardent, was first mixed with water and then the powdered Xanthin Gum added to the solution in a blender. Special care was taken to prevent the formation of any lumps in the blended material. Subsequently, nematodes were suspended in this formulation and kept aerated until their application. Aeration in the field was obtained using an aerator attached to the car's 12 V battery. The spraying method was similar to that used in Trial 2. Treatments were applied at 3 distinct growth stages of cabbage i.e. post seedling, pre heading and heading stages with concentrations of 0.25, 0.37 and $0.5 \times 10^6$ nemas/plant respectively. Sprays were applied during particularly overcast evenings to minimize desiccation of nemas. Plants were also treated with Dipel at the dosages given in Table 8.4 as a standard for comparison. All sprays were applied to run off. Each plant received 100, 150 and 200 ml of spray material at 3 successive growth stages,

respectively. Climatic data collected from nearest meteorological station at the Hobart airport is presented in Table 8.1. Assessment of pest damage and marketability of heads was performed by the methods adopted previously (cf. Chapters 6,7).

Table 8.1 Climatic conditions at the time of sprayings and post sprays in cabbage plots.

| Conditions | Post seedling | | Pre heading | | Heading | |
|---|---|---|---|---|---|---|
| | 4/11 | 7/11 | 5/12 | 9/12 | 12/1 | 15/1 |
| Air temperature (C) | | | | | | |
| Max. | 17 | 18 | 20 | 15 | 18 | 25 |
| Min. | 6 | 8 | 10 | 8 | 11 | 9 |
| Relative humidity (%) | | | | | | |
| Max. | 90 | 83 | 87 | 89 | 92 | 83 |
| Min. | 55 | 42 | 52 | 51 | 42 | 15 |
| Rainfall (mm) X | 17.4 | | 23.4 | | - | |
| Wind speed and direction | calm | calm | calm | gusty NW | calm | gusty NW |

X Figures indicate totals of 4-5 days rainfall.

8.2.1.3.4 Trial 4. S.J.F. College, 1985

The efficacy of S. feltiae and Dipel, applied alone or in combination against CWB larvae on cabbage, was evaluated in cabbage plots at S.J.F. College. Test plots were established by transplanting 16 cabbage (var. Beauty) seedlings/plot (2x2m) in 50-cm plant to plant or row to row spacing laid out in randomized complete block design with 3 replicates/treatment.

Plants were kept free from aphid infestation by the

systemic pirimicarb sprays. Plants were irrigated with sprinklers according to need. Treatments were applied during cupping stage when larval population density exceeded 1 larva/plant. Treatments and their dosages are shown in Table 8.6. Each plant received ca. 150 ml of spray formulation.

Efficacy of the treatments was evaluated by examining 16 plants per treatment for live and dead larvae and/or pupae 3 and 10 days after treatments. Subsequently, infections were confirmed either by rearing or dissection of collected individuals. Plants were also ranked for defoliation damage on the 1-6 scale described in Chapters 6 and 7.

### 8.2.2 Evaluation of entomopathogenic fungi against cabbage aphids

#### 8.2.2.1 Source of fungi and preparation

Two isolates of V. lecanii consisting of:

(a) Vertalec (FI32) on mycological agar (Oxoid Ltd., London) and

(b) VLME isolated from potato aphid, Macrosiphum euphorbiae were obtained from Dr. R.J. Milner, Division of Entomology, CSIRO, Canberra.

The fungus was grown on potato dextrose agar in petri dishes (100×15mm) at room temperature for 7-14 days. Subsequently, 10 ml sterile distilled water was added to each petri dish to wash the fungal cultures and collect the spore suspensions. Spores were harvested from the

dishes using a bent glass rod. The spore suspensions were cleared of hyphal debris by filtering through a fine cheese cloth (Hall, 1976) and used for dipping or spraying tests. Spores in the suspension were counted using a haemocytometer(Assistant,Doub Neubauer Ruling,Germany).

8.2.2.2 Laboratory tests to determine fungal infection

8.2.2.2.1 Trial 1. Direct dipping of aphids

Twenty 3rd-4th instar apterae CA, collected from aphid rearing cages in the insectary were dipped in a spore suspension of ca. $4 \times 10^5$ spores/ml of each isolate for 10 sec and then replaced on cut cabbage leaf discs (n=10) placed on soaked Whatman no.2 filter paper (9-cm) in the petri dishes. There were 2 leaf discs in each petri dish. Filter papers were moistened and leaf discs were carefully changed at 3, 7 and 10-day intervals, respectively. Sterile distilled water was used as controls. Petri dishes were incubated under laboratory conditions for 14 days. Both old and newly born aphids were examined under a binocular for mortality/infection on 3rd, 7th and 14th days after treatment.

8.2.2.2.2 Trial 2. Spray application on aphids, 1984

Cabbage seedlings (var. Ballhead) were transplanted into 15-cm plastic pots and regularly treated with nutrient solution Aquasol. Three weeks after transplanting, 20 aphids (3rd-4th instars) were placed on each of 15 plants and allowed to establish for 2 days. Aphids and plants were then sprayed to run-off using a

compressed gas spray apparatus (Jet-Pak Power Unit, Wattyl, Sydney) atomizing 15 mls of a spore suspension ($4 \times 10^5$ spores per ml) added with 0.1% v/v Teepol as thickener. The controls were sprayed with sterile water+thickener. All plants were covered with clear plastic containers or polyplastic bags to maintain a long period of high humidity. Plants were regularly watered. This trial lasted for 15 days before the counts of mortality/infection of aphids were made.

8.2.2.3 Field Trial S.J.F. College, 1985

Cabbage plots were established at S.J.F. College during the summer 1985 to test the effect of V. lecanii against field populations of cabbage aphid. Spore suspensions of Vertalec+thickener were sprayed onto cabbage plants. Sprays were applied when the plants were in post seedling to early cupping stages and the average aphid density was 23 aphids/plant. The methods and amounts of spray material were similar to those used under laboratory conditions. Plants were left exposed and not covered as in laboratory Trial 2. For the sake of comparison, plants were also treated with systemic pirimicarb (0.5 mg W.P. per plant) sprays containing the thickener. Water+thickener sprays were used as controls. Aphid counts were made on the 4th, 9th and 14th day after treatments.

## 8.3 Results

### 8.3.1 Efficacy of nematodes against lepidopterans

In laboratory tests both DM and CWB larvae proved susceptible to both strains of nematodes as well as Dipel. Nematodes weakly attacked DM pupae but not CWB pupae (Table 8.2).

The data presented in Table 8.3 show that nematodes of both strains were able to disperse from impregnated sponges and consequently infected the DM larvae. More S. feltiae nemas were retained in the sponges with significantly higher survival than S. bibionis 2 days after treatment (DAT). No nemas of any strain were found in sponges 10 DAT. In contrast, more nemas of S. bibionis were recovered by plant washing but the proportion of live nemas of S. feltiae was significantly higher ($P<0.05$) 2 DAT but significantly lower than S. bibionis at 10 DAT.

Spray applications of aqueous suspensions of both nemas during post seedling-early cupping stage did not cause any mortality of DM larvae or pupae. However, 42 and 24% CWB larval mortality was caused by S. feltiae and S. bibionis 3 DAT respectively. No live nemas of any strain were recovered by washings on 3 or 10 DAT (Table 8.4).

Successful parasitization of lepidopterans was achieved with the addition of adjuvants particularly during pre heading and heading stages (Table 8.5). Most of the CWB and DM larvae feeding on the outer foliage and wrapper leaves were susceptible to both strains. The nemas of S. feltiae were more effective than S. bibionis in causing significantly higher mortality of DM and CWB

Table 8.2 Infection of DM and CWB larvae and pupae by entomopathogenic nematodes and Dipel treatments in Petri dishes.

| Treatment | Dosage per ml of suspension | % Infection of DM | | % Infection of CWB | |
|---|---|---|---|---|---|
| | | Larvae | Pupae | Larvae | Pupae |
| S. feltiae | $1 \times 10^3$ nemas | 100(15) | 13.3(15) | 100(25) | 0(16) |
| S. bibionis | $1 \times 10^3$ nemas | 100(15) | 6.6(15) | 100(25) | 0(16) |
| Dipel | 1mg (4320 i.u) | 100(15) | 0(15) | 100(25) | - |
| Water (control) | - | 0(15) | 0(15) | 0(20) | 0(10) |

X : Values in parentheses represent the total treated individuals in respective treatments.

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Table 8.3 Parasitism of DM larvae and pupae on cabbage plants by the infective juvenile nemas applied in impregnated polyfoam sponges and their survival (Kingston, Feb. 1983).

| Treatment | X D.A.T. | Parasitism (%) | | Y Survival of nemas (%) | |
|---|---|---|---|---|---|
| | | Larvae | Pupae | Per sponge | Per plant washing |
| S. feltiae | 2 | 15(84) | 0(75) | 39a(6032) | 38a (1467) |
| | 10 | 15(111) | - | 0c(0) | 4c (519) |
| S. bibionis | 2 | 22(44) | 0(47) | 20b(2685) | 32b (3070) |
| | 10 | 28(139) | - | 0c(0) | 7c (1585) |

X : D.A.T = Days after treatment
Y : Means in columns followed by the same letter do not differ significantly ($P>0.05$) by Duncan's MRT. Numbers in parentheses represent total individuals recorded.

Table 8.4 Parasitism of DM and CWB larvae and pupae on cabbage plants sprayed with aqueous suspensions of infective nemas and their survival.

| Treatment | X D.A.T. | Y Parasitism % | | | Survival of nemas % |
|---|---|---|---|---|---|
| | | DM | | CWB | |
| | | Larvae | Pupae | Larvae | Per plant washing |
| S. feltiae | 3 | 0(11) | 0(11) | 42a (25) | 0 |
| | 10 | 0(18) | - | 18a (14) | 0 |
| S. bibionis | 3 | 0(11) | 0(15) | 24a (25) | 0 |
| | 10 | 0(18) | - | 0b (14) | 0 |

X : D.A.T = Days after treatment
Y : Means in column followed by the same letter do not differ significantly ($P>0.05$) according to Duncan's MRT. Numbers in parentheses represent total individuals examined for infection.

Table 8.5 Mortality of CWB and DM larvae and pupae on cabbage plots sprayed with formulations of entomopathogenic nematodes and Dipel (Bt) and their relative effectiveness. (CSIRO Experimental Station, 1983-84).

| Treatment[1] and formulation | Dosage/ plant | % Infection of CWB Larvae | CWB Pupae | DM Larvae | DM Pupae | % Marketability |
|---|---|---|---|---|---|---|
| | | | Post-seedling | | | |
| Sf + Ar | $0.25X10^6$ nemas | 50(6) | - | 25(4) | 0(4) | |
| Sb + Ar | $0.25X10^6$ nemas | 100(2) | - | 20(10) | 0(2) | - |
| Bt + Ar | 2 mg | 40(5) | - | 31(3) | 0(3) | |
| Control (water) | - | 0(3) | 0(1) | 0(27) | 0(15) | |
| | | | Pre heading | | | |
| Sf + Ar,Xn,Fo | $0.37X10^6$ | 60.6b (33) | 0(6) | 25b (20) | 2.7a (37) | |
| Sb + Ar,Xn,Fo | $0.37X10^6$ | 60b (35) | 0(4) | 20b (15) | 0b (53) | - |
| Bt + Te | 3mg | 93a (29) | 0(6) | 44a (16) | 4.4a (45) | |
| Control (water) | - | 0c (30) | 0(4) | 0c (16) | 0b (14) | |
| | | | Heading | | | |
| Sf + Ar,Xe,Fo | $0.5X10^6$ | 14.5b (330) | - | 0(3) | 0(1) | 60 ab |
| Sb + Ar,Xe,Fo | $0.5 X10^6$ | 11.2b (366) | 0(2) | 0(2) | - | 55 ab |
| Sf + Ar | $0.5X10^6$ | 4.7c (169) | - | 0(2) | 0(2) | 40 b |
| Sb + Ar | $0.5X10^6$ | 6.3c (173) | 0(3) | 0(4) | - | 34 b |
| Bt + te | 4 mg | 46a (89) | - | 0(4) | 0(4) | 75 a |
| Control (water) | - | 0d (45) | 0(7) | - | - | 5 c |

1 Sf - Steinernema feltiae ; Sb - Steinernema bibionis ;
Bt - Bacillus thuringiensis ; Ar - Arlaton 0.1% V/V;
Xe - Xanthin Gum 0.25%(W/V) ; Fo - Folicote 1 %(W/V) ;

larvae during pre heading and heading stages, respectively.

Dipel treatments gave significantly (P=0.05) higher mortalities of CWB and DM larvae during pre heading and CWB larvae during heading stages. This was also reflected in numerically higher but non-significant marketability of cabbage heads obtained in Dipel treated plots. No nematode associated mortality/infection was observed in the pupae of CWB or DM except at the pre heading stage when a marginal (2.7%) mortality of DM pupae was caused by S. feltiae infection. No phytotoxic symptoms were observed after any treatment in this study.

In trial 4, all treatments with nematodes and/or Dipel provided adequate control of CWB larvae during post seedling to early cupping stages (Table 8.6). The differences among mean mortalities of larvae in nematode and/or Dipel treated plots were non significant and no evidence of a synergistic effect on the efficacy of nematodes applied in combination with Dipel was detected. In fact, Dipel alone caused numerically higher mortality than all other treatments. The effect of CWB larval mortality, however, corresponded to non-significant damage ratings in treated plots.

### 8.3.2 Efficacy of V. lecanii against aphids

Dipping aphids in spore suspensions of both isolates of fungi caused significant aphid mortality indicating the viability of the fungal spores (Table 8.7). Maximum mortality of aphids was observed on 7th DAT when 95% of Vertalec treated aphids exhibited growth of fungal

Table 8.6 Field evaluation of entomogenous nematode, S. feltiae and Dipel applied alone or in combination against CWB larvae infesting vegetative growth stage of cabbage at S.J.F. College (1985).

| Treatment | Dosage/plant | CWB Larval mortality (%) | Damage rating |
|---|---|---|---|
| S. feltiae | $0.5 \times 10^6$ nemas | 68 a[X] | 2.9+0.24 a |
| Dipel | 3 mg (12960 i.u) | 78 a | 3.0+0.60 a |
| S. feltiae + Dipel | $0.5 \times 10^6$ nemas + 3 mg (12960 i.u) | 70 a | 2.9+0.61 a |
| Water(control) | - | 0 b | 3.9+0.57 b |

X = Means in column followed by the same letter are not significantly different (P>0.05) by Duncan's multiple range test.

Table 8.7 Infection of cabbage aphids, B. brassicae, dipped in the spore suspensions of two isolates of V. lecanii.

| Treatment | Dosage/ml (spores) | % Aphid mortality/infection | | |
|---|---|---|---|---|
| | | Days after treatment | | |
| | | 3 | 7 | 14 |
| Vertalec (F132) | $4 \times 10^5$ | 70 a | 95 a[x] | 95 a |
| V. lecanii (VLMC) | $4 \times 10^5$ | 60 a | 70 a | 70 a |
| Distilled water (control) | - | 0 b | 5 b | 10 b |

x = Means in a column followed by the same letter do not differ significantly (P>0.05)according to Duncan's multiple range test.

mycelium on their body and particularly on their appendages (Fig. 8.2).

Spray application under high humidity levels with viable spores of Vertalec and VLME caused significant mortality in aphid population. There was no significant difference in the performance of the 2 strains but aphid mortality due to VLME isolate was consistently lower than that of Vertalec (Table 8.8). The aphid parasitoid, D. rapae, emerged from both treated and untreated aphid hosts which indicated no deletarious effect by the pathogen.

Figure 8.3 shows that Vertalec failed to suppress aphid population under field conditions when compared with pirimicarb which provided consistent suppression of aphids upto 14 DAT.

The number of aphids increased in the Vertalec treated plots indicating lack of infectivity by the fungus. No fungal infection/growth was found on any aphid even 14 DAT.

Fig. 8.2. Infected cabbage aphid showing extensive mycelial growth of *Verticillium lecanii* .

Table 8.8 Infection of cabbage aphids, B. brassicae sprayed with spore suspensions of two isolates of V. lecanii (covered test).

| Treatment | Dosage/ml (spores) | % Aphid mortality | | No. D. rapae emerged |
|---|---|---|---|---|
| Vertalec (F132) | $4 \times 10^5$ | 96(84) | a | 4 |
| V. lecanii VMLE | $4 \times 10^5$ | 55(127) | a | 6 |
| Distilled water (control) | - | 3(268) | b | 11 |

x

x = Means in a column followed by the same letter do not differ significantly ($P>0.05$) according to Duncan's multiple range test. Values in parentheses represent the aphid numbers examined for fungal infection.

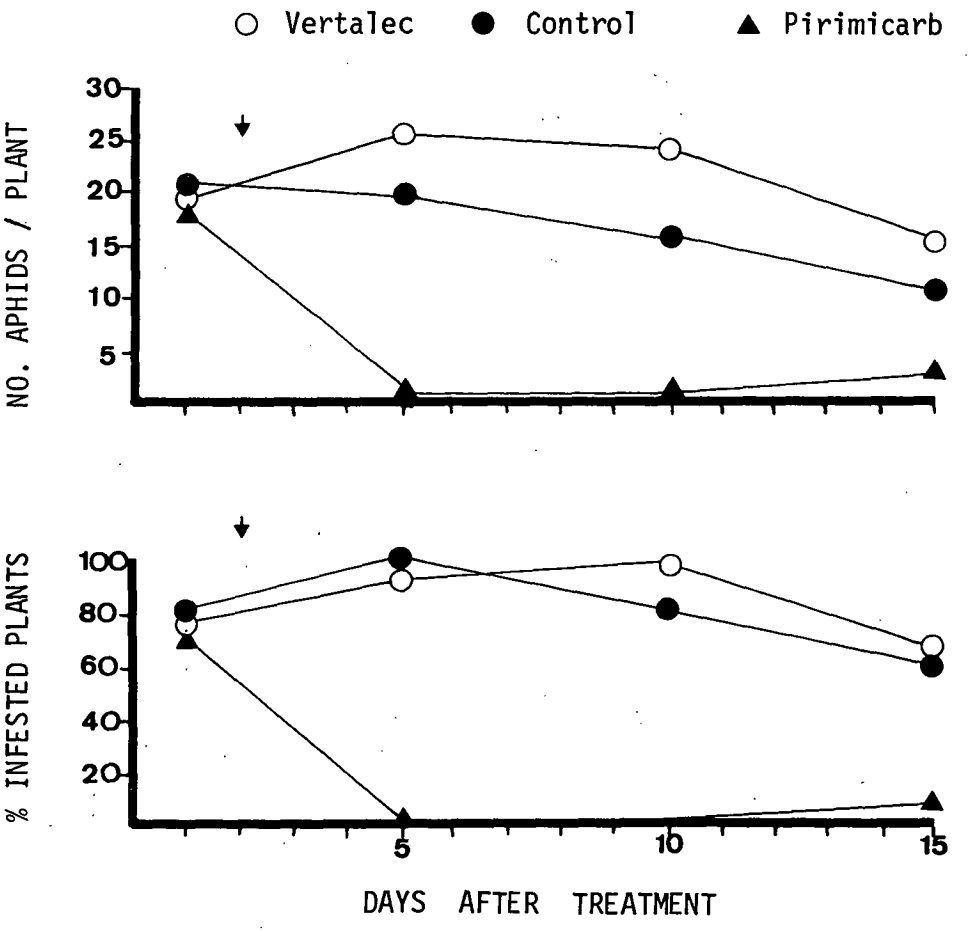



Fig. 8.3. Suppression of cabbage aphid with Vertalec and pirimicarb at S.J.F. College experimental plots.
↓ .....Spray day

## 8.4 Discussion

This investigation indicates that the effective use of entomopathogenic nematodes and fungi under field conditions is dependent upon :

(a) accurate timing of application when major proportion of the pest population is easily accessible by the pathogen and

(b) presence of optimum moisture and temperature i.e. lack of drying condition, on or around the substrate.

The enhancement of parasitization with the addition of adjuvants was because of reduced desiccation and increased adherence (see also Shapiro et al., 1985) of the infective nemas to the cabbage foliage. However, this phenomenon was limited in duration through changes in the growth phenology of cabbage plants as the results were no better than those obtained by the use of Dipel. Relatively, more open foliage of cabbage during seedling-cupping stages did not allow favourable microhabitat for nematode survival. However, the more compact pre heading stage could retain enough moisture (films) and enhanced nematode mobility/infection. This is particularly an important concept to be applied under commercial situations where growers may be encouraged to maintain optimum humid conditions through mild but regular overhead sprinkler irrigations. Previously, Welch and Briand (1961) have considered that nematode attributed mortality of caterpillars was more pronounced in the heading stage than in the open foliage stages.

A major limitation for the potential effectiveness of nematode was exhibited by decrease in infection of pest larvae in heading stage. This may be attributed to possibly an excessive $CO_2$ concentration among the layered head leaves or a differential $CO_2$ gradient between the layered leaves compared with the amount of $CO_2$ produced by the larval host (e.g. Gaugler et al., 1980). These conditions differ from those in pre heading stage where the larvae feeding on the outer foliage and wrapper leaves were susceptible to infective nemas.

Strong behavioural sensitivity of DM larvae to nematode thrusts could have hindered nematode penetration into the larval hosts. Further investigations are required to explain this phenomenon. Non-susceptibility of DM pupae to nemas is in agreement with the results obtained by Morris (1985). Better performance of S. feltiae than S. bibionis is attributed to its relatively less susceptibility to fluctuating moisture levels. Recently, Reardon et al. (1986) reported that infective juveniles of S. feltiae were less sensitive to moisture levels than S. bibionis which was also reflected in their respective effectiveness against gypsy moth larvae in the field. In contrast, Bedding and Miller (1981) attributed a superior performance of S. bibionis to S. feltiae against the currant borer moth, to the rapid attraction of its infectives into the infested stem and subsequent movement towards the host larvae.

The lack of synergism from the nematode plus Dipel combination sprays was consistent with the results

obtained by Bari and Kaya (1984) who reported that combination of nematode, S. feltiae, and B.t. did not result in significantly greater control of the artichoke plume moth than that obtained by the nematode used alone. Jaques and Morris (1981) outlined the effects that could result when two or more microbial agents are utilized in combination.

Although the application of entomopathogenic nematodes may be integrated with certain chemical insecticides (e.g. Lam and Webster, 1972; Hara and Kaya, 1982) their extensive use may not be dependable against CWB and/or DM infestations throughout the crop growth with currently available application technology. In this situation, the most pressing research need may be to develop both desiccation and chemical insecticide resistant nemas as well as their economic storage and transport.

This investigation shows that V. lecanii, despite its good performance against aphids under higher humidity in covered tests, holds little potential for use under outdoor conditions in Tasmania. Success under outdoor conditions depends upon optimum night temperatures and humidity levels for infection and the day time conditions for survival of fungus (Dr. R.J. Milner, CSIRO Division of Entomology, Canberra, Pers. comm., 1985). The fungus is reported to have humidity and temperature requirement of 10-12 h daily above 85% R.H. and a minimum temperature of 14°C (Hall et al., 1982). Such conditions are rarely experienced under Tasmanian conditions. Furthermore, these outdoor parameters can not be readily manipulated as the

weather conditions are often unpredictable and apparently unfavourable to the fungus.

The results indicated that V. lecanii may be employed against cabbage aphid infestations under glasshouse conditions where optimum levels of humidity and temperature may enhance the epizootic efficacy of this fungus with non-deleterious effects on the aphid parasitoids. However, an understanding of the relationship between the fungus and the parasitoid is necessary for their combined use against aphid infestations under glasshouse conditions (see also Harper and Huang, 1986).

# CHAPTER 9

# EVALUATION OF RESISTANCE IN CABBAGE CULTIVARS TO ATTACK BY CABBAGE INSECT PESTS

## 9.1 Introduction

Commercial growers in Tasmania prefer a range of cabbage cultivars of varying colour, texture and size and shape of the marketable product. However, the relative tolerance or resistance of these cultivars to pest attack is not yet known. Obviously, it was important to evaluate whether differences in the response to pest attack existed between cultivars. Plant characteristics, such as the waxiness of the foliage, have been associated with the variation in susceptibility to pest attack (e.g. Thompson, 1963) and resistant cultivars were reportedly found to have about half the wax that was found on susceptible plants (Cole and Rollason, 1984). An investigation was therefore made to compare different conventional cabbage cultivars with varying plant and head attributes for their susceptibility and performance against pest attack.

## 9.2 Materials and Methods

### 9.2.1 Selection and planting of cabbage cultivars

Seven cabbage cultivars were selected to represent a range of conventional types on the basis of colour and glossiness of the foliage and the shape and size of the marketable product (Cabbage head). The characteristics of the experimental cultivars are presented in Table 9.1. Waxiness/ glossiness was determined by visual differentiation of leaf colour and

Table 9.1 Colour and glossiness of the foliage and head type of the experimental cabbage cultivars planted for the evaluation of resistance to insect pest attack at the University farm (1984).

| Cultivar | Colour | Glossiness / foliage type | Head type | Source* of seeds |
|---|---|---|---|---|
| Red Pickling | Purple-red | Very glossy & thick foliage | Tight globular | 1 |
| Sugarloaf hybrid | Bright-green | Glossy & soft leaves | Conical | 2 |
| Full Irish | Yellowish green | Moderately waxy & thick leaves | Conical | 3 |
| Greengold hybrid | Light green | Thick waxy & thick leaves | Conical | 2 |
| Ballhead hybrid | Green with white veins | Thick waxy & leathery leaves | Flattened ball | 3 |
| Golden Acre | Dark green with green veins | Light waxy & leathery leaves | Tight globular | 3 |
| Savoy King hybrid | Dark green | Glossy & coarsely blistered leaves | Flattened ball | 3 |

* 1 = Hortico (Aust.) Pty. Ltd; Raymond Rd; Laverton North Victoria.
2 = Arthur Yates & Co. Pty. Ltd. 244 Horsley Rd; Miperra N.S.W. 2214
3 = Ch. Cresswell & Co. 94 Grove Road, Glenorchy, Tasmania 7010.

Seedlings were grown in the soil-peat mixture (cf. Chapter 6) in plastic trays (30X5X5 cm) in the glasshouse. Pyrethrum sprays were applied to maintain the seedlings free of initial aphid infestation. Five weeks old seedlings were transplanted to the experimental plots (3X3 m/plot) in a 7X7 Latin square design (Fig. 9.1) i.e. each plot contained 7 rows, 0.5 m apart, each row containing 7 plants of different cultivars. Adjacent plots were 1 m apart. There were 6 replications. Commercial practices were followed for the optimum growth of plants. No insecticide was applied.

| | | | | | | |
|---|---|---|---|---|---|---|
| A | B | C | D | E | F | G |
| B | E | A | G | F | D | C |
| C | F | G | B | D | A | E |
| D | G | E | F | C | B | A |
| E | D | B | C | A | G | F |
| F | C | D | A | G | E | B |
| G | A | F | E | B | C | D |

Fig. 9.1. Experimental arrangement of cabbage cultivars in the 7X7 Latin square design at the University Farm (1984). Cultivars are denoted as : A...Red Pickling ; B...Savoy King (hybrid) ; C...Sugarloaf (hybrid) ; D...Full Irish ; E...Golden Acre ; F...Greengold (hybrid) ; G...Ballhead (hybrid) .

### 9.2.2 Population estimates

On each sampling/counting occasion, which varied from 10-14 days, 21 plants of each cultivar were examined and all stages of insect pests, number of leaves per plant and stage of plant growth were recorded. Cultivars were

categorized for feeding damage or insect infestation using a severity scale of 0-3 modified from Chalfant and Brett (1967) i.e.

0 = no damage to head and surrounding leaves,
1 = < 10% head or surrounding leaves damaged,
2 = 11-30% head or surrounding leaves damaged and
3 = 31-100% head or surrounding leaves damaged.

Cabbage heads ranking 0-2 on the severity scale were regarded as marketable. Earliness or duration of each cultivar to 50% marketable heads was recorded. Percentage data were transformed to arcsine transformation before analysis.

## 9.3 Results

### 9.3.1 Pest abundance

Relative abundance of three insect pests (CA, CWB and DM) varied considerably among different cultivars (Table 9.2). The colour or the degree of waxiness did not significantly influence the host selection (colonization) by CA alates. The numbers of alate aphids were the highest on Savoy King followed by Red Pickling and Ballhead cultivars. These cultivars also had the highest apterous aphid densities. Sugarloaf had significantly (P=0.05) lower numbers of alate and apterous aphids than Savoy King and Red Pickling respectively. Interestingly, the ratio of alate and apterous CA (A:N) was the lowest in Full Irish and the highest in Red Pickling. Purple-red was the least

Table 9.2 Mean numbers of insect pest stages/plant/week on seven cultivars of cabbage in experimental plots at the university farm (1984).

| Cultivar | Cabbage aphid | | | White butterfly | | | Diamondback moth | | |
|---|---|---|---|---|---|---|---|---|---|
| | Alate (A) | Apterae (N) | A:N | Egg (E) | Larvae (L) | E:L | Larvae (L) | Pupae (P) | L:P |
| Red Pickling | 8.8 | 341.6 | 1:39 | 0.2 | 2.0 | 1:10 | 1.1 | 0.7 | 1:0.63 |
| Savoy King hybrid | 10.9 | 257.9 | 1:24 | 2.9 | 5.2 | 1:1.79 | 0.4 | 0.1 | 1:0.25 |
| Sugarloaf hybrid | 3.0 | 54.0 | 1:18 | 2.9 | 6.9 | 1:2.37 | 1.4 | 1.8 | 1:1.28 |
| Full Irish | 5.9 | 78.3 | 1:13 | 2.0 | 6.1 | 1:3.05 | 1.1 | 0.3 | 1:0.27 |
| Golden Acre | 6.6 | 194.9 | 1:29 | 3.1 | 3.8 | 1:1.22 | 0.7 | 0.4 | 1:0.57 |
| Greengold hybrid | 3.5 | 119.7 | 1:34 | 3.2 | 6.3 | 1:1.96 | 0.8 | 0.7 | 1:0.87 |
| Ballhead hybrid | 7.1 | 244.5 | 1:34 | 1.9 | 3.4 | 1:1.78 | 0.5 | 0.4 | 1:0.80 |
| L.S.D. (P=0.05) | 6.8 | 204.0 | | 2.42 | 3.9 | | 1.1 | 1.0 | |

preferred colour for oviposition by CWB females compared with green and significantly (P=0.05) lower numbers of eggs were laid on Red Pickling than on 4 out of 6 green cultivars. Glossiness or waxiness did not influence the numbers of eggs laid on a particular cultivar. A similar trend was found in the case of CWB larvae but the egg : larvae ratio for Red Pickling cultivar showed a relatively higher persistence of CWB larvae than in any other cultivar. The lowest numbers of DM larvae were recorded on Ballhead followed by Greengold and Savoy King cultivars. Highest DM larval and pupal ratios were found in Sugarloaf (1:1.3) and Greengold (1:1) cultivars.

### 9.3.2 Yield factors

Table 9.3 shows the yields of the experimental cultivars. Although the number of non-head leaves per plant in cultivars were not significantly different the total plant weight of Red Pickling and Full Irish at harvest was significantly lower (P=0.05) than all other cultivars with the exception of Sugarloaf. The total weight of a cultivar was consistent with the head weight. The number of non-head leaves (X) were negatively correlated ($r=-0.7003$, $P<0.05$, $Y=116.6-4.417X$) to the proportion of head weight to the total weight (Y).

Red Pickling took the longest time to mature followed by Ballhead and Savoy King cultivars. Full Irish matured and senesced earlier than all other cultivars. All cultivars varied in size texture and shape of the head.

Table 9.3 Yield parameters and developmental time of experimental cabbage cultivars at the University farm (1984)

| Cultivars | Per Plant | | | Productivity index B/A X 100 | Weeks to Maturity |
|---|---|---|---|---|---|
| | No. leaves (non-head) | Total weight (kg) (A) | Head weight (kg) (B) | | |
| | | * | | | |
| Red Pickling | 12.0 | 0.61 b | 0.40 b | 65.5 | 15 |
| Savoy King hybrid | 14.0 | 1.22 a | 0.72 a | 59.0 | 13 |
| Sugarloaf hybrid | 12.0 | 1.06 ab | 0.70 a | 66.0 | 12 |
| Full Irish | 11.0 | 0.67 b | 0.48 b | 71.6 | 11 |
| Golden Acre | 12.0 | 1.40 a | 0.79 a | 56.4 | 12 |
| Greengold hybrid | 13.0 | 1.40 a | 0.83 a | 59.2 | 12 |
| Ballhead hybrid | 13.0 | 1.51 a | 0.82 a | 54.3 | 14 |

* Means in the same column, followed by the same letter are not significantly different ($P>0.05$, Duncan's multiple range test).

### 9.3.3 Pest damage and marketability of cabbage heads

Figure 9.2 presents the damage rating for lepidopterous and aphid pests. Feeding damage by lepidopterans increased relatively with increase in the waxiness of the experimental cultivars and the most glossy cultivars e.g. Red Pickling and Savoy King were the least damaged. However, this tendency did not occur in the case of aphid infestation as Red Pickling and Savoy King were among the most susceptible cultivars.

Despite the greater damage by lepidopterans, Ballhead and Greengold provided the highest number of marketable heads (Fig. 9.2). In contrast, Red Pickling and Full Irish gave the lowest marketability. About 20% of the maturing heads of the Full Irish cultivar cracked in response to sudden increase in temperature thereby degrading their marketability. In Red Pickling cultivar even very low aphid infestations in the tightly wrapped head leaves lowered their marketable value. Hybrid cultivars were mainly better than pure line cultivars with respect to uniformity of growth, maturity and marketable yield.

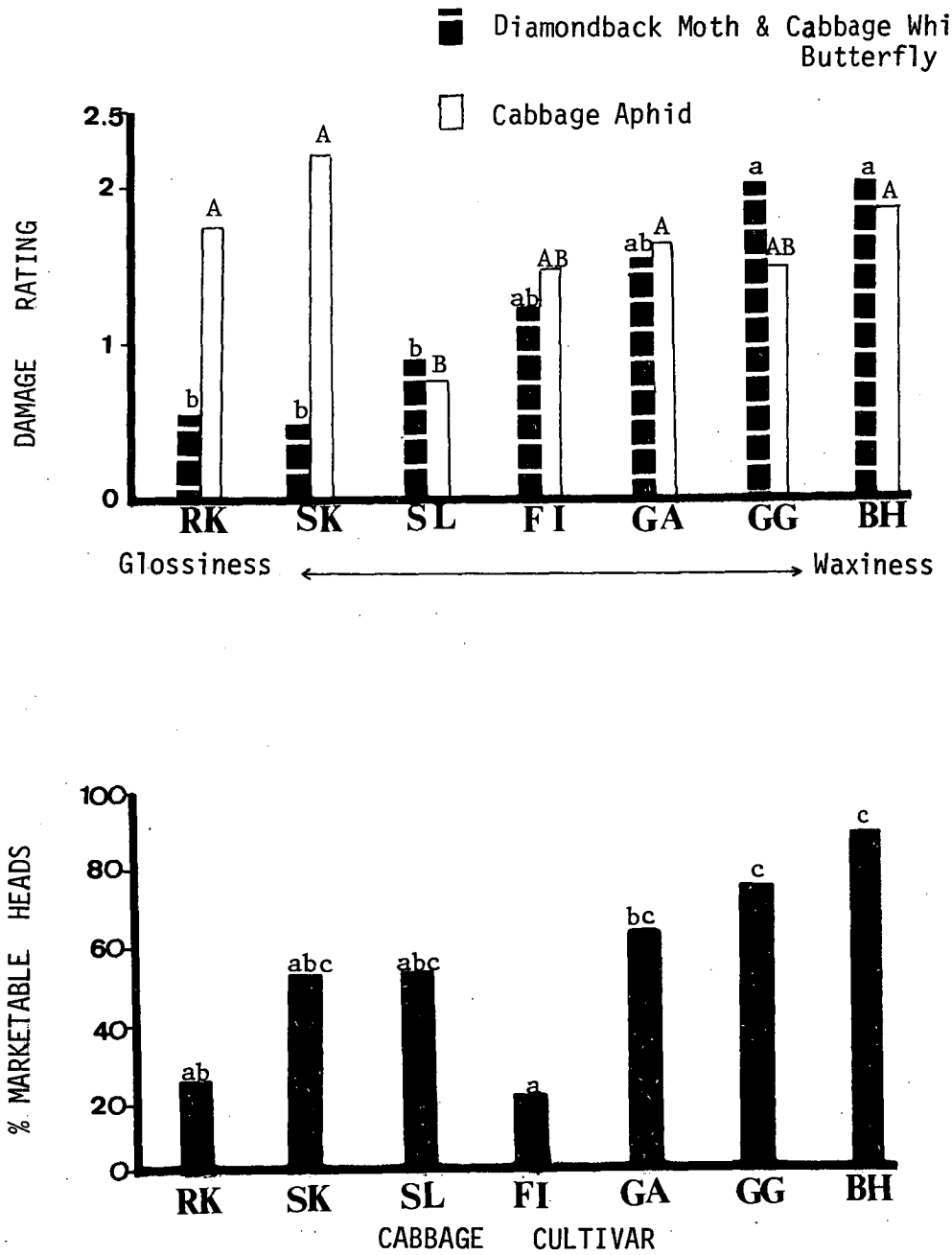



Fig. 9.2. Damage rating and marketability of heads of cabbage cultivars in response to insect pest attack at the University Farm experimental plots.
Bars with same letter are not significantly different ($P \geq 0.05$, Duncans multiple range test).

RK....Red Pickling
SK....Savoy King
SL....Sugar Loaf
FI....Full Irish
GA....Golden Acre
GG....Green Gold
BH....Ballhead Hybrid

## 9.4 Discussion

This investigation suggests that non-preference may be more important than other forms of resistance e.g. tolerance and antibiosis (Painter, 1951) for the insect pests of cabbage. It is evident that the selection of a particular host cultivar by the insect does not imply that the selected host was the most suitable cultivar for subsequent feeding and development. Initially, the ovipositing or colonizing parents responded to the ovipositional/colonization cues of a particular cultivar rather than its suitability i.e. nutritive value, etc. In other words plant attributes of a cultivar such as growth form, foliage texture and leaf glossiness or waxiness were more important in influencing the host selection behaviour and numbers of insects than its nutrition or chemical factors. Chemical factors of the cultivars were not examined in this study and remain to be investigated. Harrison and Bubaker (1943) reported that the abundance of lepidopterous larvae on cabbage was dependent on the amount of foliage, plant maturity, height of plants and general physical condition.

The presence of the wax bloom on the leaf surface or possibly its constituents were responsible for enhanced larval damage. This tendency was further supported by the fact that CWB females laid relatively fewer eggs on the most glossy Red Pickling cultivar. Similar ovipositional behaviour was also reported by Dickson and Eckenrode (1975) and Dunn and Kempton (1976). The eyes of CWB have been reported to contain a visual pigment which may absorb

red wave length (Bernard, 1979) and any difference in the host reflectance may be perceived before or at the time of oviposition. In the present investigation, the reflectance properties of the experimental cultivars were not quantified. Measurement of attributes such as plant pigments, leaf thickness, wax bloom density, chlorophyll, anthocyanins, etc., is important to relate the host reflectance and insect response (Dr. Peter Vickery, Principal Research Scientist, Pastoral Research Laboratory, CSIRO, Armidale, N.S.W, Pers. comm., 1985).

The results on the relative abundance of CA on Red Pickling are contrary to those reported by Radcliffe and Chapman (1966) who found that red cabbage was least preferred by CA for colonization. However, the present investigation confirms their conclusion that the red cabbage was most favourable to aphid increase once it was infested. This may well be attributed to the relatively richer nutritional contents in the red cabbage than green cabbage (e.g. Patton and Green, 1954).

With respect to the CA, colour or the waxiness of the cultivars as visual cues were not significant factors in host selection, thus CA and CWB have different strategies for selection of cabbage host. Despite the general complexity involved in identifying the factors confering resistance to any cultivar, it was evident from the results that such factors as colour, waxiness and nutritive value are the important characteristics of cabbage which influenced the abundance of insect pests on this host plant.

# CHAPTER 10

# CHEMICAL CONDITIONING OF THE CABBAGE PLANT AND SUPPRESSION OF INSECT PEST NUMBERS

## 10.1 Introduction

Although increased waxiness of leaves was shown to result in increased damage by CWB and DM larvae, it is not known whether this is a direct surface effect or one indirectly associated with host plant physiology. Little data are available on the manipulation of host plant physiology and its effect on pest abundance and behaviour.

In previous trials on pest population abundance (Chapter 4) and resistance of cabbage cultivars (Chapter 9) it had been observed that CWB tended not to oviposit on plants infested with either DM larvae or CA. It was hypothesized that previously infested plants contained or carried materials which inhibited the normal oviposition behaviour of CWB. Subsequent investigations generated a series of additional hypotheses and these provided the basis of this study in which general objectives were to :

(a) gain an appreciation of the role of wax or leaf surface components with respect to insect pest response;

(b) identify structural, physiological and chemical changes in the plant surface following alteration in physiology and

(c) examine the potential of the non-destructive

alterations in host characteristics which may have significant effect on pest behaviour under field conditions. A knowledge of the mechanisms involved could provide a better general understanding of host plant selection by insects.

## 10.2 Materials and Methods

### 10.2.1 General

#### 10.2.1.1 Plant material

Cabbage plants of Ballhead cultivar, unless otherwise stated, were used in all experiments for rearing insects, collection of headspace volatiles and extraction of cuticular components. For indoor trials plants were first grown in plastic trays under glasshouse conditions with supplementary lighting and then transplanted into sterilized sand in 15-cm clay pots. Water and nutrient solutions were always applied through the glass dishes under the pots and never sprayed on the foliage. For field trials, commercially grown cabbage plants were used.

#### 10.2.1.2 Test insects

For behavioural assays, CA, CWB or DM were obtained from laboratory maintained cultures in separate rearing cages. Field-collected fresh individuals were only used when the laboratory stock was in short supply.

### 10.2.1.3 Collection of insect frass and preparation of extract

Larvae and frass of DM and frass of CWB were collected from infested plants in cabbage fields at Kingston in stoppered glass bottles containing n-pentane (A.R. solvent, Ajax chemicals, Sydney, Australia). The material was stored in dry ice and returned to the laboratory. Larvae and frass were macerated in the solvent and the filtered extracts stored in a freezer (-4 °C) until use.

### 10.2.1.4 Examination of leaf surface

Leaf pieces (1cm), upper and lower surfaces, from the 3rd and 4th leaves of pentane sprayed and control cabbage plants were attached to the upper surface of the double sided silver metallic tape (3M) attached to aluminium SEM stubs following gold coating. Scanning electromicrographs of both leaf surfaces were taken using a Phillips 505 SEM camera to examine the pattern of wax bloom in pentane sprayed and control plants.

### 10.2.1.5 Collection of leaf volatiles

The method used by Chesterman (1982) was employed to prepare the volatile trapping system which is diagramatically shown in Figure 10.1. Sample collection tubes (traps) consisting of glass lined tubing and containing Tenax G.C. were used. Technical details of the material involved are given in the Appendix 10.1. Purified air was passed over the plant foliage in collection chamber and exhausted through the Tenax traps by applying

suction to the outlet of the traps. Suction was obtained and regulated by a water tap manifold. The system was run for 6,12 or 48 h. Traps were individually packed in aluminium foil and stored in stoppered glass containers in the freezer until the desorption of volatiles occured.

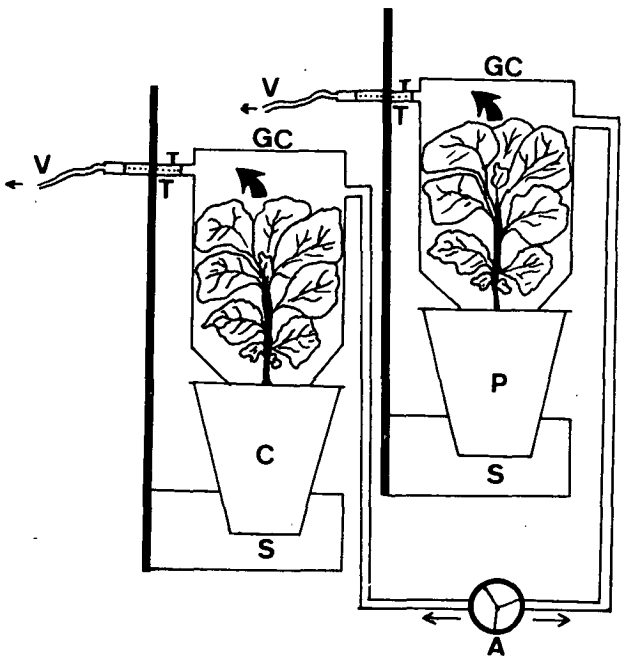



Fig. 10.1. Diagramatic representation of the Tenax trapping system for the collection of cabbage leaf volatiles:

| | |
|---|---|
| C | Untreated plant |
| P | Pentane treated plant |
| A | Gas inlet |
| GC | Glass chamber |
| S | Iron stand |
| T | Tenax trap |
| V | Outlet to vacuum (suction pressure) |

10.2.1.6 Identification of volatile components

Collected volatiles were first desorbed by the method of Chesterman (1982) and then eluted into GC-MS for characterization. The combined GC-MS facility at the Central Science Laboratories (CSL), University of

Tasmania, was used for this purpose. Technical details of the system are given in Appendix 10.1. Identification of different components (peaks) were made by comparison with mass spectral data obtained from published works and library search facilities at the CSL (i.e. Heller and Milne, 1978) and tentatively when the mass spectrum could not be identified positively.

10.2.1.7 Water status of the solvent treated plants

Diffusive resistance or the water status of the pentane treated and control plants was measured with a Ll-COR Autoporometer Model Ll-700 (Ll-COR Inc. Nebraska, U.S.A). Measurements were made on each leaf of the treated and control plants. There were 3 replications per treatment.

10.2.1.8 Inhibition of epicuticular wax formation

Potted cabbage plants were treated with ethofumesate, (2-ethoxy-2,3 dihydro-3, 3-dimethyl-S-benzofuranyl methane sulfonate), a herbicide which has been reported to inhibit the wax deposition on cabbage leaves (Robert et al., 1978). Ethofumesate 20 E.C. was applied either through the soil (5 ml of herbicide in 10 ml of water/plant) or sprayed on the foliage (5 ml/plant of the solution used for soil treatment). Teepol® (0.2%) was used as sticker in sprays. For comparison, plants were also sprayed with pentane. Plants were grown under glasshouse conditions in the insect proof screened cages for a week before their use in bioassays.

### 10.2.1.9 Extraction and identification of cuticular components

#### 10.2.1.9.1 Extraction procedure I

Leaves of the pentane and ethofumesate treated and untreated plants were excised with their petiole without causing any injury to the leaf lamina and were allowed to wilt slightly to ensure stomatal closure (Flore and Bukovac, 1974). Cotton wool was wrapped around the petioles and the leaves of each treatment were dip-washed in 1.5 l pre sterilized wide-head glass bottles containing 500 ml methanol. The bottles were shaken for 10 min in a bar agitator operated at a very slow speed.

After the washing, the extracts were filtered through folded Whatman no.1 filter papers. Methanol was evaporated under vacuum in a rotary evaporator (Rota vapor-R, Buchi, Switzerland) at a temperature of 30°C. The remaining contents were transferred into stoppered glass bottles and stored in the freezer. Leaf areas in each treatment were calculated from the weight of the leaf outlines drawn on A-4 graph papers.

#### 10.2.1.9.2 Extraction procedure II

Similar leaves (n=12) of the pentane treated and untreated cabbage plants were washed separately in large jars (2-l) in a bar agitator for 10 minutes. The following solvents were used individually:-

(a) Water (1_1);

(b) Methanol (1_1) and

(c) Chloroform (1-1).

Following the extraction, the leaves were allowed to dry and their respective areas measured as previously described. Extracts were filtered, reduced to near dryness in the rotary evaporator and rediluted with 10 ml water and cold stored in stoppered glass bottles (10-ml) until use. The water bath temperature during evaporation was 50, 30 and 25°C for water methanol and chloroform solvents respectively.

10.2.1.10 Thin layer chromatography (TLC)

The separation of the cuticular components into major chemical classes was made by TLC using Kieselgel 60 (Silica Gel) 20X20 cm plates (Art.5721, Merck, Darmstadt). The plates, pre washed in chloroform and oven-dried at 110°C for 24 h , were loaded with individual extracts using a Rodder/Streaker (Rodder Instruments, Calif. U.S.A.) and developed for 2 h in benzene-chloroform (7:3 v/v) in rectangular glass chromatography tank. Following a run, the plates were removed from the tank and air-dried to remove the mobile phase of the solvents. Localization of different components was detected under short wave (254 nm) or long wave (365 nm) ultraviolet radiation. The positions of separate zones (RF values) were calculated by the following formula :

$$Rf = \frac{\text{Distance of the zone from the starting streak}}{\text{Distance travelled by the solvent front}}$$

Specific separate zones were individually scraped with

J-shape knife and the collected material washed with 5 ml chloroform to elute the components, dried and then redissolved in 1 ml chloroform and transferred into stoppered glass vials which were stored in the freezer for GC-MS analysis.

10.2.1.11 Gas chromatography/mass spectrometery

Different fractions of the TLC separated components were analyzed on a Hewlett-Packard 5890 gas chromatograph. Technical details of the system are given in Appendix 10.2. Other procedures were the same as employed in the identification of volatiles using the facilities at the CSL.

10.2.1.12 Analysis of data

The data were analyzed either by ANOVA or Student's t-test. Percentage data was transformed (arcsine transformation) before analysis and means were compared using Duncan's multiple range test. For other data, means and standard errors are tabulated and levels of significance refer, in instances of heterogeneous data, to analysis of the data following log (x + 1) trans- formation. Such analyses are tabulated on opposite pages.

10.2.2 Experimental Laboratory bioassays (I-II)

10.2.2.1 Oviposition by CWB on plants treated with frass and larval extracts (bioassay no.I)

The hypothesis that the presence of CWB or DM larvae and their frass contained certain material which inhibited the normal oviposition behaviour of CWB was tested in this bioassay. Pentane extracts of larvae and frass (5 ml/plant) were sprayed onto cabbage plant foliage using a

Jet-Pak power unit sprayer (Wattyl, Sydney, Australia). A second series of plants was sprayed with solvent alone. Water sprays were used as control. Two hours later the plants were exposed to 6 gravid CWB females in each screened laboratory cage (60X75X100cm). There were 3 plants representing each treatment in each cage. There were 4 replications/treatment. The positions of the plants interchanged after every 30 min to avoid any edge effect. The bioassay lasted for 4 h. Subsequently, the plants were examined for eggs. The same methodology was adopted for subsequent laboratory bioassays which examined the effects of pentane and wax inhibitor treatments.

#### 10.2.2.2 Bioassay no.2 Ovipositional response of CWB on upper or lower leaf surface

In the previous trial, it was observed that CWB and CA oviposit/larviposit on both upper and lower surfaces of cabbage leaves. To ascertain any behavioural difference in the oviposition by CWB females on the upper and lower surfaces of pentane treated and untreated leaves, plants were exposed to gravid CWB females (n=13) for 24 h. Each treatment had 4 replicates. Plants were later examined for eggs on both surfaces of leaves.

#### 10.2.2.3 Bioassay no.3 Ovipositional response of DM on upper or lower leaf surface

In this test ovipositional behaviour of DM females was assessed on the upper and lower surfaces of the leaves of pentane treated and untreated plants. Plants were exposed to the gravid DM females (10/cage) for 24 h. Each treatment was tested with 4 replicates. Plants were later examined for eggs on both sides of leaves.

### 10.2.2.4 Bioassay no.4 Colonization and larviposition response of CA

As in Bioassay no. 3 pentane treated and untreated plants were exposed to 300 alate CA. Counts of colonizing alate aphids or nymphs produced were made on both upper and lower surfaces. Each treatment was tested with 4 replicates. The number of alates that settled in relation to the number of deposited nymphs was taken as an index of acceptability for the respective treatments (e.g. Moon, 1967).

### 10.2.2.5 Bioassay no.5 Response of insects on wax inhibited plants

The hypothesis that disorientation or inhibition of epicuticular wax bloom causes a suppression of normal oviposition behaviour of CWB and colonization larviposition of CA was tested in this bioassay. Cabbage plants were treated with ethofumesate, either through the soil or sprayed on the foliage, and pentane spray. Water spray was used as control. There were 5 replicates/ treatment. A week later, plants were arranged on wooden benches in a temperature controlled glasshouse (2.5X4m). Male (n=15) and female (n=21) CWB and alate CA (n=450) collected from stock cultures were released in the centre of the experimental benches. Honey solution (10%) for CWB adults was provided on soaked yellow sponges in the petri dishes on raised posts around the plants. Ambient temperature was 22±3°C under natural photoperiod conditions. Plants were rotated 90 counter clockwise every hour during the day to randomise the effects of any possible extraneous environmental influences (e.g. Feeny et al., 1970). The trial lasted for 48h before the plants were examined for CWB eggs and alate or nymphal CA.

#### 10.2.2.6 Bioassay no.6 Feeding response of CWB larvae

The hypothesis that the disorientation of epicuticular wax and/or induced changes in host plant physiology affect the feeding response of the insect was tested in this bioassay. Pentane sprayed and unsprayed plants in the 5-6 leaf stage were infested artificially with newly hatched 1st instar CWB larvae (5 larvae/plant). One larva was placed on each leaf and allowed to feed for 7 days before the surviving larvae were recorded and the counts of feeding holes made. There were 10 replicates per treatment.

#### 10.2.2.7 Bioassay no.7 Colonization and larviposition of CA and oviposition of CWB

This test was carried out to confirm the relative suppression of colonization and larviposition by CA and oviposition by CWB. Pentane treated and untreated cabbage plants were exposed to 250 CA alates and 27 (17♀ ,10♂ ) CWB. Other conditions were similar to those employed in Bioassay no.1. There were 12 replicates per treatment. The trial lasted for 48 h. CWB eggs were counted after every 6 hours and removed from the leaves with a fine camel hair brush to avoid any crowding effect. Aphids were left undisturbed on the foliage. Counts were made on both upper and lower leaf surfaces.

### 10.2.2.8 Bioassay no. 8 Ovipositional response of CWB to allyl isothiocyanate

An attempt was made to test whether the cabbage volatile allyl isothiocyanate (ATC) played any role in the orientation of gravid CWB females to lay their eggs. This was tested in two ways :

(a) allyl isothiocyanate treated Whatman filter paper no. 2 circles (10-cm) were placed on vertical stakes attached to wooden bases. The circles were kept moist throughout the test. Water soaked circles were used as control,

(b) leaves of a non-cruciferous plant, Bergenia schmidtii (Regel), Silva Tar, (Saxifragaceae) which were morphologically very similar to cabbage leaves in colour, shape and texture were systemically treated with ATC aqueous suspension by inserting their petioles in a 100 ml beaker containing 50 ml of 0.01% ATC. Petioles were allowed to dry before being offered on wooden posts to CWB females.

Each cage contained a pair of treated and untreated filter paper circles or Bergenia leaves. Newly emerged and mated CWB females were released in the cages (4/cage). There were 4 replicates for each treatment. The trial lasted for 6 h.

10.2.2.9 Bioassay no. 9 Oviposition of CWB and colonization and larviposition of CA on cabbage plants treated with leaf extracts

The hypothesis that the cuticular components of cabbage leaves enhance the oviposition by CWB and colonization and larviposition by CA was tested in this bioassay. Water, methanol and chloroform extracts of cabbage leaves were sprayed (7.5 ml/plant) on cabbage plants in 5-6 leaf stage. There were 3 plants per treatment. Treated plants were exposed to 10 gravid CWB females and 100 CA alates in the glasshouse. The trial lasted for 48h before counts of CWB eggs and alate and apterous CA were made.

10.2.2.10 Bioassay no.10 Oviposition of CWB on cabbage plants treated with water extract of control and pentane treated plants.

Following the observation that water extracts of cabbage leaves enhanced CWB oviposition, this test was carried out to confirm the additive role of control plant extract in comparison to pentane treated plant extract. Cabbage plants were treated with water extracts of control and pentane treated plants (7 ml/plant) and exposed to 16 gravid CWB females in the glasshouse. Water sprays were used as control. There were 4 replicates/treatment. The trial lasted for 24h before egg counts were made.

10.2.2.11 Bioassay no.11 Larviposition of CA in response to leaf extracts

This test was designed to determine whether wax constituents of pentane treated and untreated plants, extracted by different solvents, could stimulate progeny production by CA. Water, methanol and chloroform extracts (7.5 ml/treatment) of pentane treated and untreated plants were sprayed on 15 leaves (0.5 ml/leaf) on 5 plants. Each plant possessed one control (untreated) leaf. Virginoparae apterous female aphids were obtained from the stock culture in petri dishes, kept without food for 2 hours and then placed in aphid leaf cages (2 aphids/cage) on each treated or control leaf (single-choice test). The numbers of adult aphids that settled and nymphs deposited were recorded after 24, 48 and 96h for the bioassay involving water extracts of control and pentane treated plants. The effect of methanol and chloroform extracts of control and pentane treated plants on the larviposition of CA was similarly evaluated in subsequent bioassays where numbers of apterae produced were recorded after 48 h. Solvent in water (50:50 v/v) was used as control in these bioassays.

10.2.3 Field trials

The induced effects of solvent sprays and wax inhibitors was further tested in field trials at the commercial cabbage fields at Campania. The main objective of these trials was to assess whether such effects had potential application in applied suppression of insect pests.

10.2.3.1 Trial. no.1 Evaluation of the solvent sprays

Sixty cabbage plants of Dutch hybrid cultivar in post seedling stage were selected in a corner of a cabbage field (30X50m). The experimental plant rows were marked with red ribbons to prevent any intrusion. The cabbage field was surrounded by other cabbage crops in different growth stages. Pentane (P) or pentane+petroleum ether (PPE) 50:50 sprays were applied using Jet-Pak sprayer in conjunction with the farmer's insecticidal sprays. Each plant was sprayed with 2-8 ml of P or PPE depending upon the growth stage of the plants.

Counts of CA (alate and apterae) and CWB (eggs and larvae) were made on solvent and commercially treated plants every 14 days. At maturity, plants were harvested and total and commercial weights assessed. Percent marketability of harvested heads were assessed as described earlier (cf. Chapter 6).

10.2.3.2 Trial no.2 Evaluation of the solvent sprays

In this trial spray applications of the solvents (pentane or petroleum ether (PPE) ) were only made when pest densities reached action threshold (cf. Chapter 7). Fortnightly, pyrethrum sprays were applied as a standard for comparison. In each treatment, there were 50 plants in 5 rows. Solvent and pyrethrum sprays were applied with controlled droplet application (CDA) Winston Technoma T5 herbicide sprayer (F.M. Winston Ltd., P.O. box 2195 Auckland, New Zealand). The assessments of pest occurrence, plant performance and marketability were similar to as described earlier.

## 10.3 Results

### 10.3.1 Response of insects on plants treated with larval or frass extracts (Bioassay no.I)

In the preliminary investigation involving the CWB ovipositional response to cabbage plants sprayed with either DM larval or CWB frass extracts, it was found that oviposition was significantly ($P<0.05$) suppressed by both extracts (Tables 10.1a 10.1b). However, a similar effect was obtained by the solvent (pentane) spray alone.

### 10.3.2 Response of insects to pentane treated plants (Bioassay no.2-4)

In subsequent bioassays, significant suppressions of oviposition by CWB and DM and larviposition by CA were obtained on pentane only sprayed plants (Table 10.2, 10.3, 10.4 ). Although the upper surface of leaves was sprayed the suppressing effect occured on both upper and lower surfaces. Both CWB and DM females responded to cabbage plants as soon as they were released into cages and landed on pentane sprayed and control plant with similar frequency but most often preferred the control plants for settling and/or oviposition. Similarly, fewer CA alates colonized pentane treated plants. Larviposition on plants was also significantly suppressed ($P<0.05$) following pentane treatment.

Examination of the upper pentane sprayed leaf surface by SEM, revealed that the epicuticular wax bloom was disoriented in comparison to untreated leaf surface (Fig.

Data in Table 10.1a transformed to Log Scale, Log (X+1)

Oviposition by CWB on caged cabbage plants sprayed with pentane and pentane extract of DM larvae.

| Treatment | Replications | No. eggs laid $\bar{X} \pm$ S.E. |
|---|---|---|
| DM larval extract | 4 | 1.115 ± 0.092 a |
| Pentane alone | 4 | 1.338 ± 0.092 a |
| Control (water) | 4 | 1.810 ± 0.092 b |

* Means with the same letter are not significantly different (P>0.05; Duncan's multiple range test).

---

Data in Table 10.1b transformed to Log Scale, Log (X+1)

Oviposition by CWB on caged cabbage plants sprayed with pentane and pentane extract of fecal pellets of CWB larvae.

| Treatment | Replications | No. eggs laid $\bar{X} \pm$ S.E. |
|---|---|---|
| Fecal extract | 4 | 0.858 ± 0.413 a |
| Pentane alone | 4 | 0.738 ± 0.201 a |
| Control (water) | 4 | 1.515 ± 0.143 b |

* Means with the same letter are not significantly different (P>0.05, Duncan's multiple range test).

---

Table 10.1$_a$ Oviposition by CWB on caged cabbage plants sprayed with pentane and pentane extract of DM larvae.

| Treatment | Replications | No. eggs laid $\bar{X}$ ± S.E. |
|---|---|---|
| DM larval extract | 4 | 13.0 ± 2.8 a |
| Pentane alone | 4 | 22.2 ± 4.0 a |
| Control (water) | 4 | 69.0 ±16.4 b |

* Means with the same letter are not significantly different (P>0.05; Duncan's multiple range test).

Table 10.1$_b$ Oviposition by CWB on caged cabbage plants sprayed with pentane and pentane extract of fecal pellets of CWB larvae.

| Treatment | Replications | No. eggs laid $\bar{X}$ ± S.E. |
|---|---|---|
| Fecal extract | 4 | 18.5 ± 10.3 a |
| Pentane alone | 4 | 7.0 ± 4.3 a |
| Control (water) | 4 | 37.8 ± 11.7 b |

* Means with the same letter are not significantly different (P>0.05, Duncan's multiple range test).

Table 10.2 Ovipositional response by cabbage white butterfly on pentane treated cabbage plants in a glasshouse cage *

| Treatment | Total no. of eggs laid | | |
|---|---|---|---|
| | Upper surface (U) | Lower surface (L) | Total (U+L) |
| Pentane spray | 12 | 2 | 14 |
| Control (water spray) | 23 | 24 | 47 |
| t-test (df=6) | n.s. | P<0.05 | n.s. |

* Equal-choice test, n.s.=not significantly differrent

Data in Table 10.3 transformed to Log Scale, Log (X+1)

Ovipositional response of DM on pentane treated cabbage plants in a glasshouse cage. *

| Treatment | No. of eggs laid/plant ($\bar{X}$+S.E.) Upper leaf surface (U) | Lower leaf surface (L) | Total (U+L) |
|---|---|---|---|
| Pentane spray | 0.30 ± 0.122 | 0.67 ± 0.083 | 1.162 ± 0.071 |
| Control (water spray) | 0.575 ± 0.119 | 1.01 ± 0.147 | 0.782 ± 0.043 |
| t-test (df=6) | n.s. | n.s. | P<0.01 |

* Equal-choice test ;
n.s. not significantly different (P>0.05)

Table 10.3 Ovipositional response of DM on pentane treated cabbage plants in a glasshouse cage. *

| Treatment | No. of eggs laid/plant ($\bar{X}$+S.E.) Upper leaf surface (U) | Lower leaf surface (L) | Total (U+L) |
|---|---|---|---|
| Pentane spray | 1.25±1.25 | 4.0±1.82 | 5.25±1.25 |
| Control (water spray) | 3.25±2.21 | 11.0±6.5 | 14.25±5.12 |
| t-test (df=6) | n.s. | n.s. | P<0.01 |

* Equal-choice test ;
n.s. not significantly different (P>0.05)

Table 10.4 Colonization and larviposition response by CA on pentane sprayed cabbage plants in a glasshouse cage. *

| Treatment | Total no. counted: Upper surface Alate (A) | Upper surface Apterae (N) | Lower surface Alate (A) | Lower surface Apterae (N) | Ratio A : N |
|---|---|---|---|---|---|
| Pentane spray | 8 | - | 73 | 6 | 0.073 |
| Control | 49 | 9 | 139 | 86 | 0.5 |
| t-test (df=6) | n.s. | n.s. | n.s. | P<0.05 | |

* Equal choice test ;
n.s. not significantly different (P>0.05)

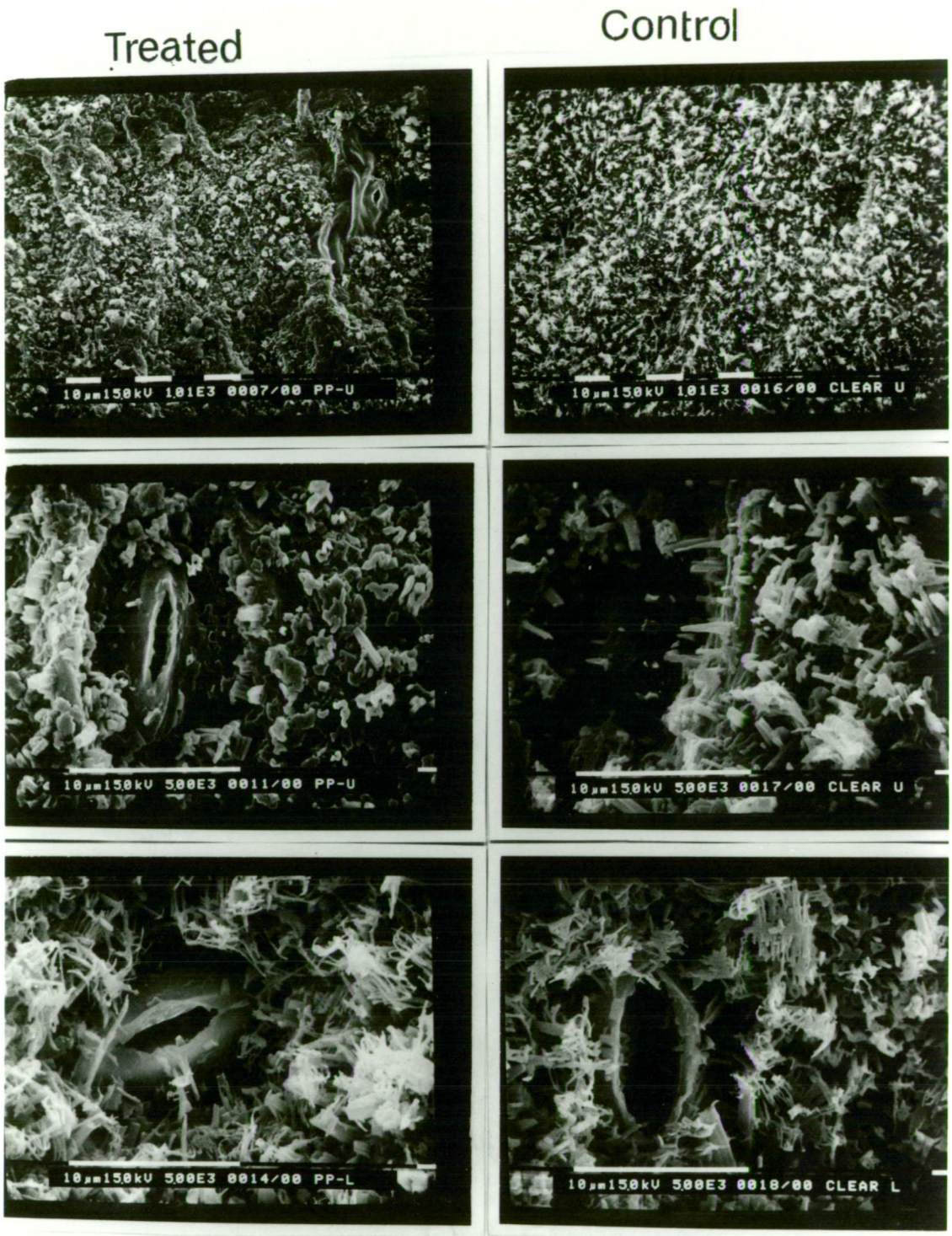



Fig. 10.2 Photomicrograph illustrating the epicuticular wax on the upper(U) and lower(L) surfaces of cabbage leaves from solvent-treated(PP) and control(clear) plants.

10.2). A marked reduction in the diffusive resistance (water status) of the sprayed plants was also recorded (Fig. 10.3), however, this reduction was more pronounced in basal (older) compared with upper (younger) leaves. The water status of the plants was also reflected in the relative size of the opening of the stomata (Fig. 10.2).

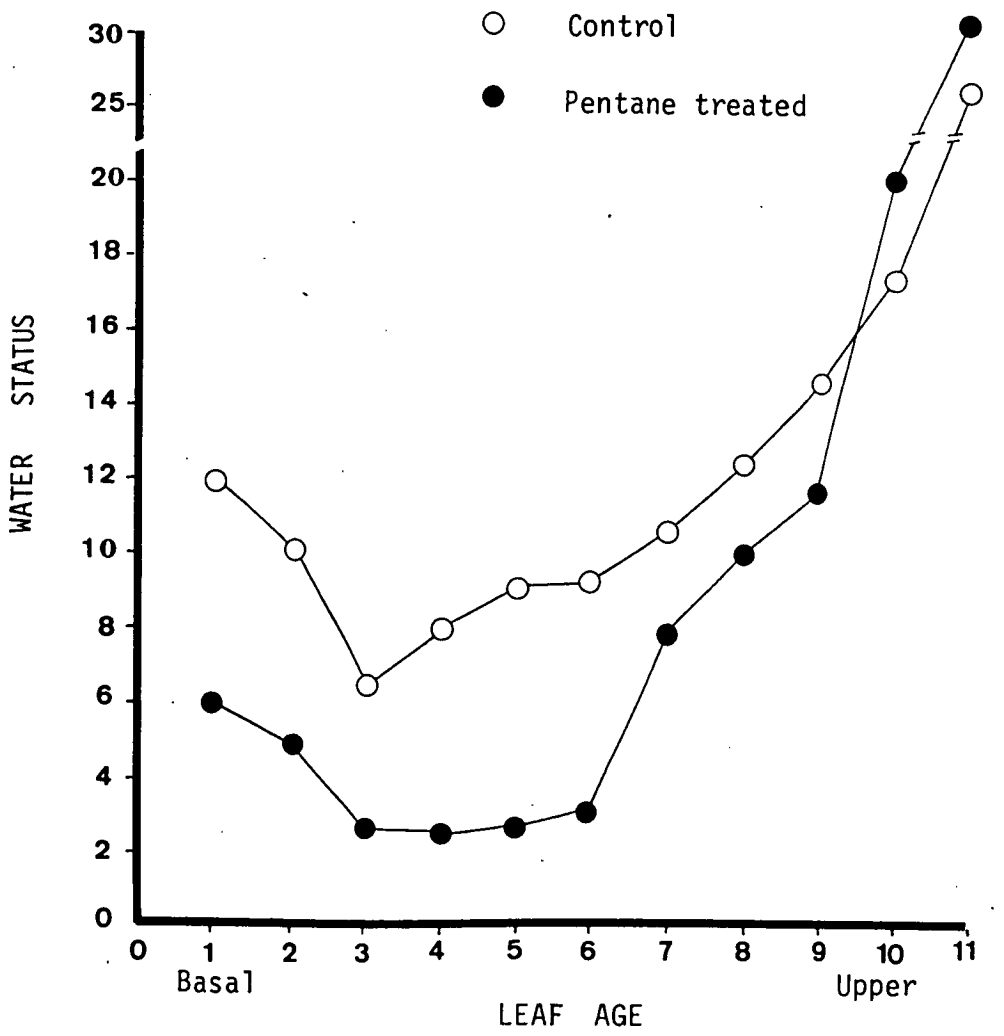



Fig. 10.3. Effect of pentane spray on the water status (Diffusive Resistance) of cabbage plant leaves.

### 10.3.3 Inhibition of wax formation and pest response (Bioassay no.5)

Treatment of plants with ethofumesate, applied either as a foliage spray or soil drench, successfully inhibited the formation of epicuticular wax. The treatment effect became apparent after 10 days.

Oviposition of CWB and CA colonization and production of apterae were significantly suppressed ($P<0.05$) on ethofumesate treated plants. Apterous production was also significantly inhibited on plants sprayed with pentane but CWB oviposition was slightly suppressed (Table 10.5).

### 10.3.4 Suppression of pest behaviour in laboratory bioassays no.6-7

A significant decrease ($P<0.01$) in the feeding response of CWB larvae occured on pentane treated plants (Table 10.6 ). Despite the initial mortality of neonate larvae in some replicates of both treatments, the survival of larvae on pentane treated plants was not significantly different ($P>0.05$) from controls.

Significantly, less CA larviposition ($P<0.005$) and CWB oviposition ($P<0.01$) were recorded on pentane treated plants exposed to both CA and CWB in the glasshouse (Table 10.7 ). The numbers of CA alates colonized on pentane treated and control plants were not significantly different ($P>0.05$). However, the total numbers of CA colonized pentane treated plants were half as many colonized control plants. Aphids were usually found to wander more and exhibited more frequent short time probes on the leaf surface of pentane treated than control plants which indicates that pentane treatment did not favour the acceptability of host to the insect.

Data in Table 10.5 transformed to Log Scale, Log (X+1)

Suppression of CWB oviposition and CA colonization and larviposition on cabbage plants treated with epicuticular wax inhibitor.

| Treatment | CWB | CA | |
|---|---|---|---|
| | No. eggs laid/ plant ($\bar{X} \pm$ S.E.) | Alate colonized $\bar{X} \pm$ S.E. | Apterae deposited $\bar{X} \pm$ S.E. |
| Ethofumesate spray | 1.338 ± 0.078 a | 0.155 ± 0.99 a | 0.06 ± 0.060 a |
| Ethofumesate soil drench | 1.397 ± 0.067 a | 0.260 ± 0.128 a | 0.216 ± 0.152 a |
| Pentane spray | 1.562 ± 0.121 a | 0.645 ± 0.124 b | 0.660 ± 0.157 b |
| Control (water spray) | 1.646 ± 0.099 a | 0.804 ± 0.058 b | 1.024 ± 0.072 c |

* Means within a column followed by the same letter are not significantly different (P>0.05 ; Duncan's multiple range test).

Table 10.5 Suppression of CWB oviposition and CA colonization and larviposition on cabbage plants treated with epicuticular wax inhibitor.

| Treatment | CWB | | CA | | | |
|---|---|---|---|---|---|---|
| | No. eggs laid/ plant ($\bar{X}$ ± S.E.) | | Alate colonized $\bar{X}$ ± S.E. | | Apterae deposited $\bar{X}$ ± S.E. | |
| Ethofumesate spray | 25.6 ± 4.18 | a | 0.6 ± 0.4 | a | 0.2 ± 0.4 | a |
| Ethofumesate soil drench | 25.6 ± 4.39 | a | 1.2 ± 0.7 | a | 1.2 ± 0.9 | a |
| Pentane spray | 41.6 ± 8.43 | a | 4.2 ± 1.4 | b | 4.8 ± 1.8 | b |
| Control (water spray) | 50.0 ±11.64 | a | 5.6 ± 0.8 | b | 8.4 ± 2.4 | c |

* Means within a column followed by the same letter are not significantly different (P>0.05 ; Duncan's multiple range test).

Data in Table 10.6 transformed to Log Scale, Log (X+1)

Effect of solvent spray on cabbage leaves on feeding by CWB larvae.

| Treatment | No. larvae survived per plant | No. feeding holes/ larva/plant $\bar{X} \pm$ S.E. |
|---|---|---|
| Pentane spray | 0.605 ± 0.034 | 0.961 ± 0.056 |
| Control(untreated) | 0.598 ± 0.046 | 0.746 ± 0.035 |
| t-test (df = 18) | n.s. | P<0.01 |

Table 10.6 Effect of solvent spray on cabbage leaves on feeding by CWB larvae.

| Treatment | No. larvae survived per plant | No. feeding holes/ larva/plant $\bar{X} \pm$ S.E. |
|---|---|---|
| Pentane spray | 3.2 ± 1.39 | 4.87 ± 1.27 |
| Control(untreated) | 3.3 ± 1.15 | 8.95 ± 3.9 |
| t-test (df = 18) | n.s. | P<0.01 |

Table 10.7 Colonization and larviposition by cabbage aphid and oviposition by white butterfly on pentane sprayed and untreated (control) cabbage plants in a glass cage.

| Treatment | No. alate aphid colonized | | Total | No. apterae deposited | | Total | No. eggs laid by butterfly | | Total |
|---|---|---|---|---|---|---|---|---|---|
| | Upper surface (U) | Lower surface (L) | (U+L) | Upper surface (U) | Lower surface (L) | (U+L) | Upper surface (U) | Lower surface (L) | (U+L) |
| Pentane spray | 15 | 26 | 41 | - | 2 | 2 | 12 | 88 | 100 |
| Control | 17 | 64 | 81 | 12 | 49 | 61 | 35 | 248 | 283 |
| t-test | (df=9) | | n.s. | | | P<0.005 | | | P<0.01 |

Data in Table 10.8 transformed to Log Scale, Log (X+1)

Oviposition of CWB and colonization and larviposition of CA on cabbage plants treated with water, methanol or chloroform extract of cabbage leaves. x

| Test material | CWB eggs | Mean no. of CA per plant ($\bar{X} \pm$ S.E.) | |
|---|---|---|---|
| | | Alates | Apterae deposited |
| Water extract | 1.133 ± 0.065 a | 0.339 ± 0.076 a | 0.813 ± 0.114 ab |
| Methanol extract | 0.953 ± 0.084 ab | 0.050 ± 0.050 b | 0.871 ± 0.072 a |
| Chloroform extract | 0.648 ± 0.211 b | 0.100 ± 0.063 b | 0.495 ± 0.129 b |

x Means within a column followed by the same letter are not significantly different (P>0.05, Duncan's multiple range test).

### 10.3.5 Response of CWB females to allyl isothiocyanate (ATC) (Bioassay no.8)

The volatile ATC did not play any role in the orientation of the gravid CWB females as no egg was laid on any ATC treated / untreated filter paper circle or Bergenia leaf.

### 10.3.6 Effect of leaf extracts on pest response (Bioassays no.9-II)

Water extract of cabbage plants was significantly ($P<0.05$) more active than chloroform extract in stimulating CWB oviposition and CA alate colonization (Table 10.8 ). However, water extract was no better than methanol or chloroform extracts for CA larviposition.

Subsequent bioassay involving water extracts of pentane treated and control plants revealed that CWB

Table 10.8 Oviposition of CWB and colonization and larviposition of CA on cabbage plants treated with water, methanol or chloroform extract of cabbage leaves. x

| Test material | CWB eggs | Mean no. of CA per plant ($\bar{X} \pm$ S.E.) | |
|---|---|---|---|
| | | Alates | Apterae deposited |
| Water extract | 13.5 ± 5.1 a | 1.3 ± 0.8 a | 6.8 ± 5.5 ab |
| Methanol extract | 8.8 ± 4.1 ab | 0.2 ± 0.4 b | 7.0 ± 3.2 a |
| Chloroform extract | 6.0 ± 5.4 b | 0.3 ± 0.5 b | 2.8 ± 2.4 b |

x Means within a column followed by the same letter are not significantly different ($P>0.05$, Duncan's multiple range test).

Data in Table 10.9 transformed to Log Scale, Log (X+1)

Oviposition by CWB on cabbage plants treated with water extracts of control and pentane treated plants.

| Test material | Mean no. of eggs laid ($\bar{X} \pm$ S.E) * | |
|---|---|---|
| | Day I | Day II |
| Control Plant extract | 1.253±0.008 a | 1.333 ± 0.063 a |
| Pentane treated plant extract | 0.973±0.030 b | 1.085 ± 0.093 b |
| Water spray | 0.897±0.149 b | 1.090 ± 0.042 b |

*Means within a column followed by the same letter are not significantly different (P>0.05, Duncan's multiple range test).

oviposition was significantly lower ($P<0.05$) on plants treated with extract of pentane treated plants than those treated with extract of control plants (Table 10.9 ).

Table 10.9 Oviposition by CWB on cabbage plants treated with water extracts of control and pentane treated plants.

| Test material | Mean no. of eggs laid ($\bar{X}$ ± S.E) * | |
|---|---|---|
| | Day I | Day II |
| Control Plant extract | 17.0 ± 0.8 a | 21.3 ± 6.7 a |
| Pentane treated plant extract | 8.5 ± 1.3 b | 12.0 ± 4.8 b |
| Water spray | 8.8 ± 8.0 b | 11.5 ± 2.4 b |

* Means within a column followed by the same letter are not significantly different ($P>0.05$, Duncan's multiple range test).

However, water extract of either control or pentane treated plants did not significantly affect CA larviposition (Table 10.10 ). In contrast, larviposition was significantly suppressed by methanol and chloroform extracts of pentane treated plants in comparison to similar extract for untreated (control) plants (Table 10.11 , 10.12 ). Furthermore, both methanol and chloroform when applied in an aqueous spray significantly suppressed larviposition when compared with the plants treated with extracts of control plants.

Data in Table 10.10 transformed to Log Scale, Log (X+1)

Larviposition by CA on cabbage leaves treated with water extracts of untreated (control) and pentane treated cabbage plants

| Test material | Mean no. of nymphs deposited per cage ($\bar{X} \pm$ S.E) * Days after treatment 1 | | 2 | | 4 | |
|---|---|---|---|---|---|---|
| Control plant extract | 1.09 ± 0.15 | a | 1.39 ± 0.13 | a | 1.23 ± 0.28 | a |
| Pentane treated plant extract | 1.03 ± 0.07 | a | 1.06 ± 0.52 | a | 1.23 ± 0.18 | a |
| Water spray | 1.00 ± 0.36 | a | 1.19 ± 0.41 | a | 1.16 ± 0.20 | a |

* Means within a column followed by the same letter are not significantly different (P>0.05, Duncan's multiple range test).

Data in Table 10.11 transformed to Log Scale, Log (X+1)

Larviposition by CA on cabbage leaves treated with methanol extract of control and pentane treated plants.

| Test material | Mean no. of nymphs deposited per leaf cage ($\bar{X} \pm$ S.E) * | |
|---|---|---|
| Control plant extract | 1.40 ± 0.040 | a |
| Pentane treated plant extract | 0.704 ± 0.118 | b |
| Methanol in water (spray) y | 0.360 ± 0.175 | b |

* Means followed by the same letter are not significantly different (P>0.05, Duncan's multiple range test).
y 50 : 50 (v/v)

Data in Table 10.12 transformed to Log Scale, Log (X+1)

Larviposition by CA on cabbage leaves treated with chloroform extract of control and pentane treated plants.

| Test material | Mean no. of nymphs deposited per leaf cage ($\bar{X} \pm$ S.E) * | |
|---|---|---|
| Control plant extract | 0.870 ± 0.076 | a |
| Pentane treated plant extract | 0.490 ± 0.147 | b |
| Chloroform in water (spray) y | 0.308 ± 0.128 | b |

* Means followed by the same letter are not significantly different (P>0.05, Duncan's multiple range test).
y 50 : 50 (v/v)

Table 10.10 Larviposition by CA on cabbage leaves treated with water extracts of untreated (control) and pentane treated cabbage plants

| Test material | Mean no. of nymphs deposited per cage ($\bar{X}$ ± S.E) * | | |
|---|---|---|---|
| | Days after treatment | | |
| | 1 | 2 | 4 |
| Control plant extract | 12.0 ± 4.1 a | 24.2 ± 6.9 a | 18.7 ± 10.2 a |
| Pentane treated plant extract | 9.7 ± 1.7 a | 21.2 ±31.1 a | 17.0 ± 6.6 a |
| Water spray | 12.5 ±12.6 a | 21.0 ±22.4 a | 14.8 ± 8.3 a |

* Means within a column followed by the same letter are not significantly different (P>0.05, Duncan's multiple range test).

Table 10.11 Larviposition by CA on cabbage leaves treated with methanol extract of control and pentane treated plants.

| Test material | Mean no. of nymphs deposited per leaf cage ( $\bar{X}$ ± S.E ) * |
|---|---|
| Control plant extract | 12.0 ± 2.7 a |
| Pentane treated plant extract | 4.8 ± 2.8 b |
| Methanol in water (spray) y | 2.2 ± 2.9 b |

* Means followed by the same letter are not significantly different (P>0.05, Duncan's multiple range test).
y 50 : 50 (v/v)

Table 10.12 Larviposition by CA on cabbage leaves treated with chloroform extract of control and pentane treated plants.

| Test material | Mean no. of nymphs deposited per leaf cage ( $\bar{X}$ ± S.E ) * |
|---|---|
| Control plant extract | 7.0 ± 3.5 a |
| Pentane treated plant extract | 2.8 ± 2.1 b |
| Chloroform in water (spray) y | 1.4 ± 1.3 b |

* Means followed by the same letter are not significantly different (P>0.05, Duncan's multiple range test).
y 50 : 50 (v/v)

### 10.3.7 Volatile components of control and pentane treated plants

Table 10.13 compares the profiles of volatile components of control and pentane treated cabbage plants and Fig. 10.4 presents their respective GC chromatographs. Although both types of plants produced similar volatiles, their levels (relative abundance) were suppressed in pentane treated plants. Distinctive groups of volatiles i.e. aldehydes alcohols, alkanes and sulphur compounds were identified. Among alcohol fractions, ethanol was slightly greater in treated plants, however, a relatively longer chain alcohol, n-butoxy ethanol was lower in treated plants. Interestingly, the level of dimethyl disulphide was about 3 times less in treated plants. Among aldehyde fractions, with the exception of 2-butenal, the level of pentenal, hexenal, octenal and nonanal were lower in treated plants. No allyl compounds from glucosinolate degradation (thiocyanate) could be detected in any treatment

Table 10.13 Identification and relative abundance of cabbage volatile sample components from untreated (Control) and pentane treated (Pentane) plants.

| Identification | Control | | Pentane | |
|---|---|---|---|---|
| | Peak no. | Relative abundance (%) | Peak no. | Relative abundance (%) |
| Ethanol 1 | 39 | 14.02 | 46 | 16.4 |
| Acetone 1 | 41 | 5.85 | 48 | 13.1 |
| Ether THF | 45 | 4.63 | 49 | 6.26 |
| Methyl acetate | 48 | 0.60 | 50 | 0.89 |
| 2-butenal 1 | 60 | 0.85 | 60 | 1.49 |
| 2-butanone 1 | 71 | 2.43 | 70 | 1.49 |
| Benzene | 90 | 0.73 | 90 | 0.59 |
| Unidentified base peak m/z 31,56 | 107 | 2.43 | 111 | 2.08 |
| Trans-pent-2-en-1-al 2 | 111 | 1.82 | 115 | 1.49 |
| Trichloroethylene | 125 | 5.12 | 127 | 3.43 |
| Heptane | 130 | 1.34 | 130 | 0.74 |
| Dimethyl disulphide 1 | 135 | 0.85 | 135 | 0.29 |
| Unidentified base peak | 138 | 0.48 | 138 | 0.14 |
| Toluene | 170 | 5.48 | 170 | 3.73 |
| Trans-hex-2-en-1-al 1 | 187 | 6.58 | 187 | 2.83 |
| Octane | 190,195 | 2.43 | 190,195 | 1.49 |
| Ketol (?) | 285 | 0.60 | 275 | 2.53 |
| n-butoxy ethanol | 286 | 3.90 | 281 | 2.98 |
| Benzylaldehyde 3 | 300 | 0.60 | 300 | 0.89 |
| Unidentified base peak | 340,350 | 1.21 | 340,350 | 1.19 |
| Octenal 2 | 370 | 2.43 | 370 | 2.08 |
| n-decane | 380 | 0.70 | 380 | 0.89 |
| Limonene | 410 | 1.34 | 410 | 1.94 |
| Nonanal | 474 | 2.43 | 465 | 1.94 |

Table 10.13 (continued)

| | Contaminants/artifacts from air or Tenax | | | |
|---|---|---|---|---|
| Chloroform | 83 | 3.65 | 88 | 4.77 |
| Silica | 200 | 1.09 | 200 | 0.74 |
| Xylene | 247,255 | 9.26 | 247,255 | 4.47 |
| ∝- pinene | 326 | 2.68 | 320 | 4.17 |
| Monoterpene (other) | 290,368, 399 | 13.03 | 285,354, 391 | 13.48 |
| Sesquiterpene | 500 | 1.21 | 500 | 1.19 |

Compounds also reported by :
1. MacLeod and MacLeod(1968)
2. Hrdlicka et al. (1969)
3. Buttery et al. (1978)

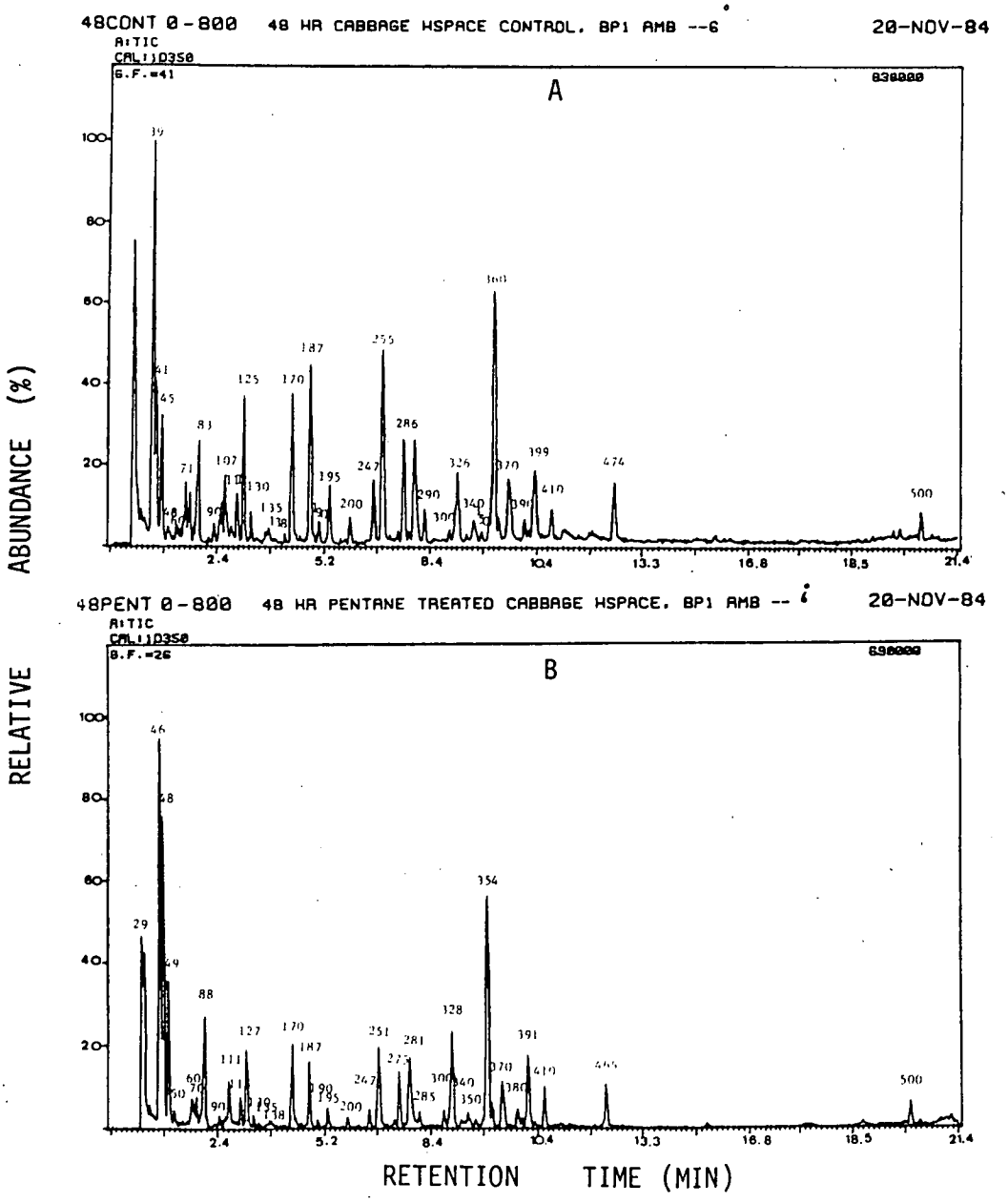



Fig. 10.4. Chromatogram of volatile samples from intact (A) and pentane treated (B) cabbage plants after 48 hours Tenax trapping. For identification of peaks see Table 10.7.

### 10.3.8 Wax components of pentane treated and control plants

Separation of the epicuticular wax of control and pentane treated plants by GC-MS into different constituents is represented in Table 10.14 and Fig. 10.5. The alkanes (heptacosane, nonacosane) were lower in treated than control plants. However, the level of nonacosan-15-one (a ketone) were not very different in the two treatments. Out of three identified aldehydes, two were found in lower levels in treated plants. In contrast, the levels of triterpenoid, $\alpha + \beta$ amyrin were 3 times higher in treated than control plants.

### 10.3.9 Effect of ethofumesate on wax constituents

Incorporation of ethofumesate into soil markedly decreased the deposition/formation of alkanes, ketones and aldehydes on cabbage leaf surface (Table 10.15, Fig. 10.6). Nonacosane level in treated plant was about half the level in control plant. Similar declines in the ketone (nonacosan-15-one) and aldehyde fractions (hexenal, hexacosanal, heptacosanal, nonacosanal and triacontanal) were recorded in treated plants. In contrast, the primary alcohol (heptacosanol) was higher in treated plants.

Better chromatographic resolutions of alkane alcohols (both primary and secondary) and aldehydes were obtained following trimethylsilylation (TMS). As in the previous analysis, ethofumesate treatment suppressed levels of

Table 10.I4 Identification and relative abundance of the constituents of surface wax extract from untreated (Control) and pentane treated (Pentane) cabbage plants.

| Identification | | Control | | Pentane | |
|---|---|---|---|---|---|
| | | Peak no. | Relative abundance % | Peak no. | Relative abundance % |
| Unidentified base peak m/z 185,259,329 | | 3 | 0.90 | 3 | 1.03 |
| Heptacosane | a | 4 | 4.21 | 4 | 3.51 |
| Hexacosanal | | 5 | 4.51 | 5 | 3.31 |
| Nonacosane | a | 6 | 39.45 | 6 | 26.50 |
| Heptacosanal | | 7 | 7.53 | 7 | 9.10 |
| Nonacosan-15-one | a | 8 | 23.79 | 8 | 25.05 |
| Unidentified | | 9 | 6.62 | 9 | 4.76 |
| Triacontanal | | 10 | 2.71 | 10 | 1.44 |
| α+β amyrin (high mass triterpenoid) | | 12 | 4.81 | 11 | 12.4 |
| Phthalates | b | 1,2 | 1.50 | 1,2 | 12.80 |
| Syringe artifact | b | 11 | 3.91 | - | - |

a . Compounds also reported by Purdy and Truter (1963) as components of cabbage wax.
b . Contaminant/artifact

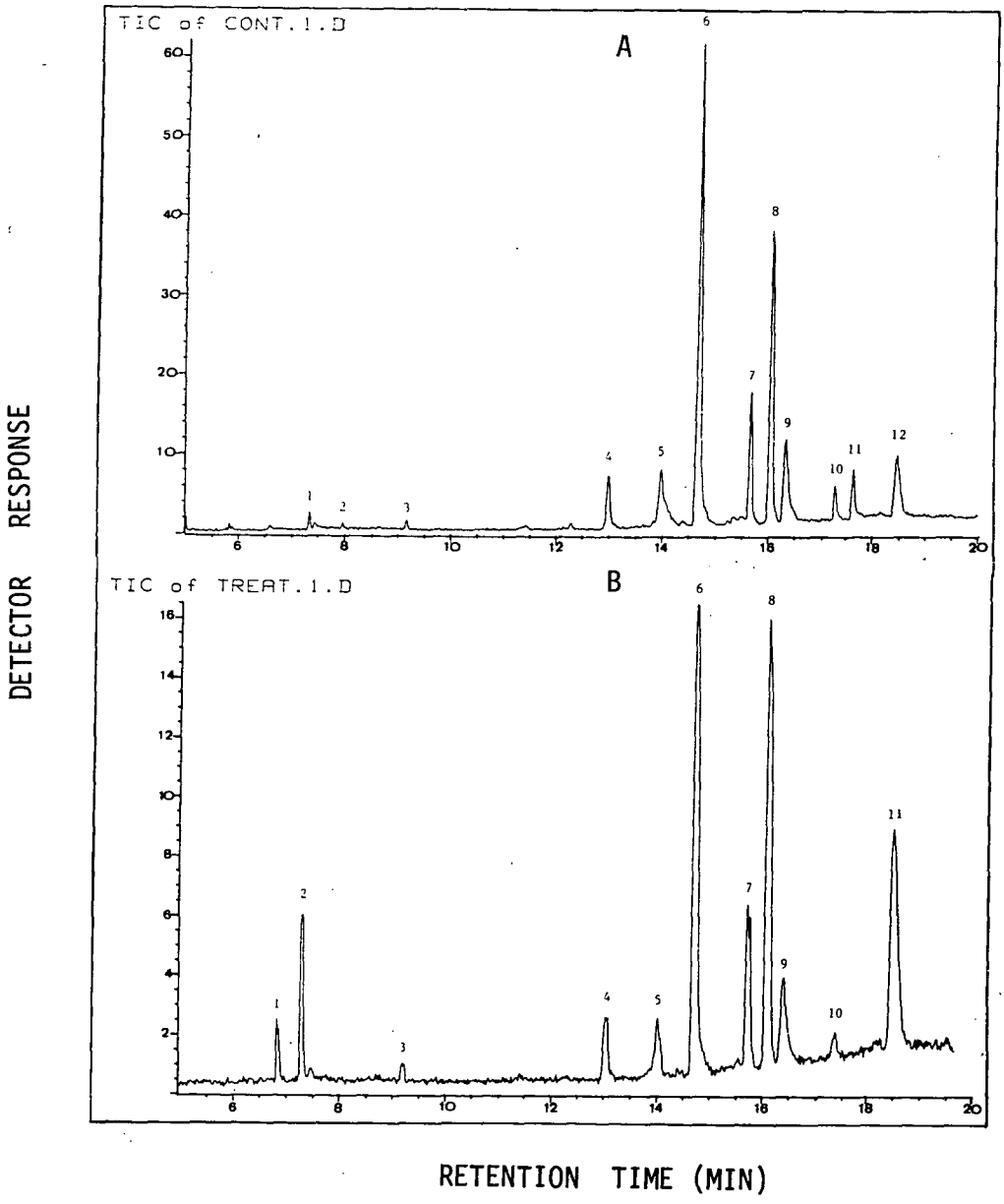



Fig. 10.5. Capillary GC profiles of the surface wax components of the untreated (A) and pentane treated (B) cabbage plants. For identification see Table 10.8.

Table 10.15 Identification and relative abundance of wax constituents of leaf surfaces of untreated (Control) and ethofumesate treated (Tramat) cabbage plants.

| Identification | Control | | Tramat | |
|---|---|---|---|---|
| | Peak no. | Relative abundance % | Peak no. | Relative abundance % |
| Unidentified base peak m/z 79,137, 161,179,207,286 | - | - | 1 | 6.62 |
| Ethofumesate (see text) | - | - | 2 | 0.66 |
| Hexanal | 4 | 1.62 | 4 | 0.66 |
| Heptacosane a | 5 | 6.09 | 5 | 5.51 |
| Octacosane a | 6 | 1.62 | 6 | 1.10 |
| Hexacosanal | 7 | 9.75 | 7 | 5.73 |
| Heptacosan-13-one | 8 | 0.81 | 8 | 1.32 |
| Nonacosane a | 9 | 48.78 | 9 | 25.38 |
| Heptacosanal | 10 | 0.81 | 10 | 0.66 |
| Heptacosanol | 11 | 1.21 | 11 | 2.20 |
| Unidentified | 12 | 1.21 | 12 | 0.66 |
| Octacosanal a | 13 | 18.29 | 13 | 13.90 |
| Nonacosan-15-one a | 14 | 40.24 | 14 | 25.60 |
| Hentriacontane a | 15 | 2.03 | 15 | 0.88 |
| Unidentified base peak m/z 213,227,241 (alcohol ?) | 16 | 1.21 | 16 | 0.88 |
| Nonacosanal | 17 | 4.87 | 17 | 3.31 |
| Triacontanal | 18 | 4.47 | 18 | 2.87 |
| Artifact (?) | 3 | 1.62 | 3 | 1.98 |

a. Also reported by Purdy and Truter (1963) as components of cabbage wax.

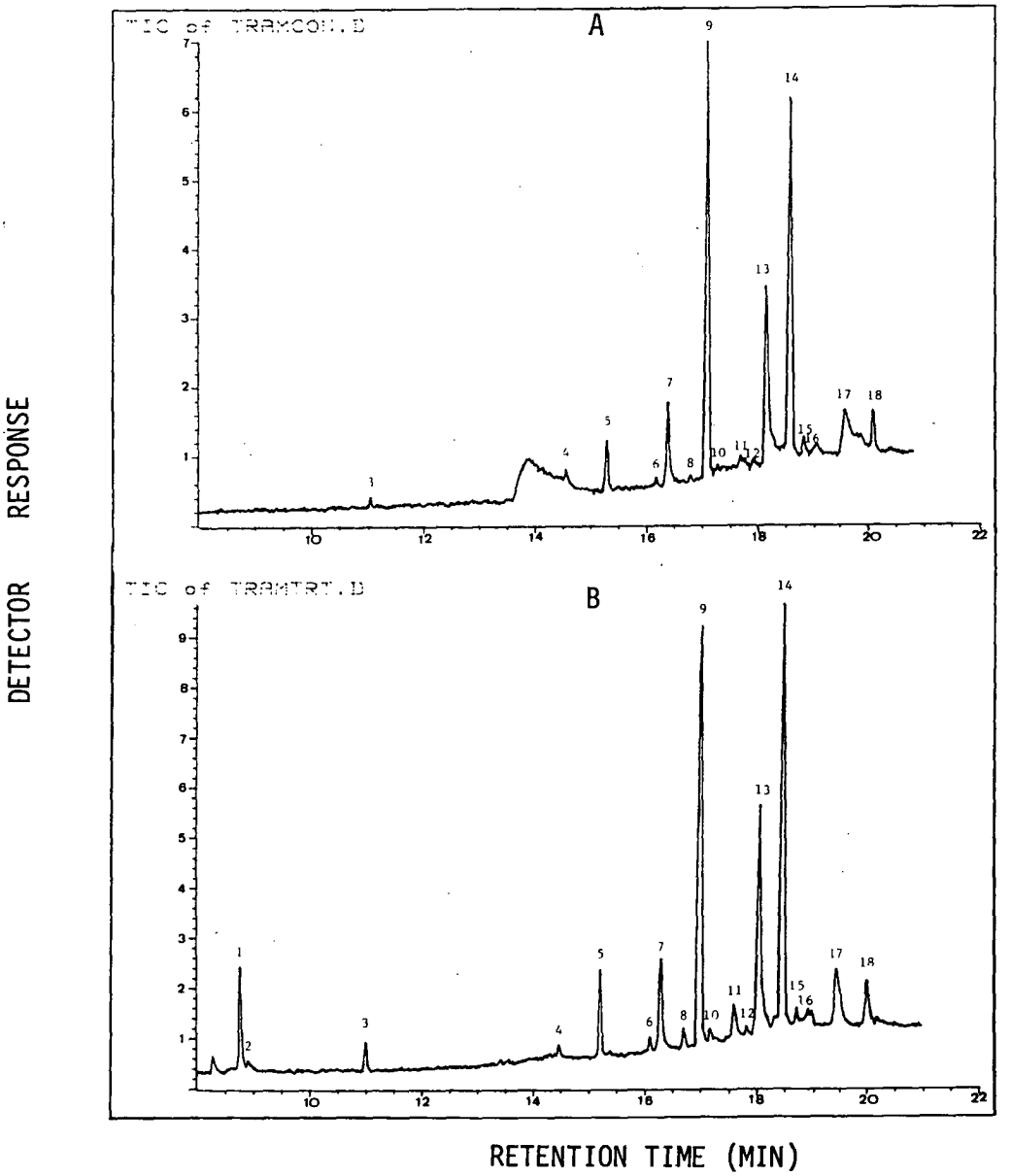



Fig. 10.6. Chromatogram of the wax constituents of leaf surfaces of untreated (A) and ethofumesate treated (B) cabbage plants. For identification of peaks see Table 10. 9.

ketones, alcohols and aldehydes however, levels of α + β amyrin were double of those in control plants. Fatty acid fractions (Palmitic and linolenic acids) were relatively higher in treated than control plants (Fig. 10.7, Table 10.16).

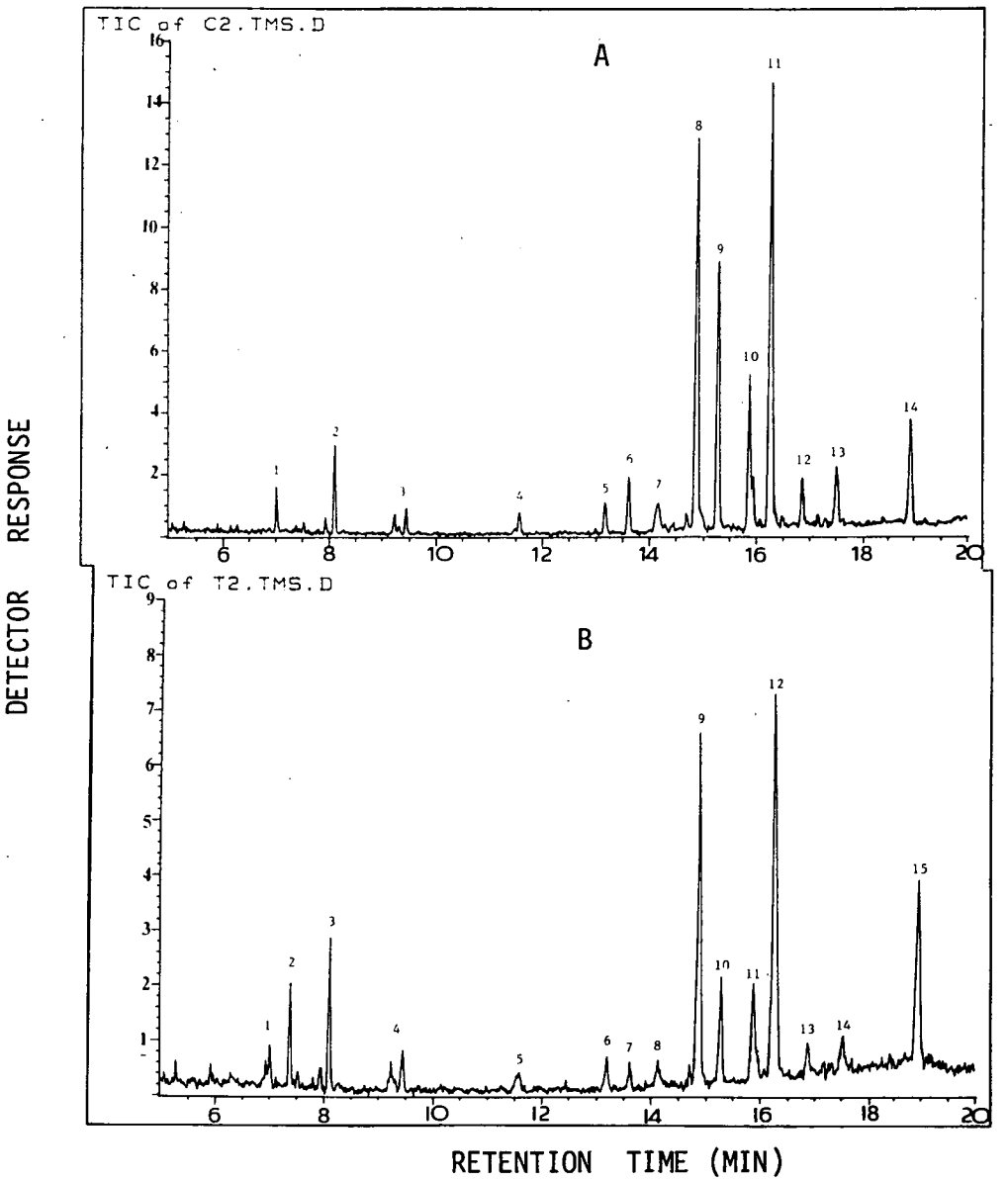



Fig. 10.7. Chromatogram of the wax constituents (trimethylsilylated) of leaf surfaces of untreated (A) and ethofumesate treated (B) cabbage plants. For identification of peaks see Table 10.10.

Table 10.16 Identification and relative abundance of the trimethylsilylated (TMS) constituent of surface wax from untreated (Control) and ethofumesate treated (Tramat) cabbage plants

| Identification | | Control | | Tramat | |
|---|---|---|---|---|---|
| | | Peak no. | Relative abundance % | Peak no. | Relative abundance % |
| Ethofumesate (see text) | | - | - | 1 | 2.70 |
| Palmitic acid | | 2 | 4.80 | 3 | 9.23 |
| Linolenic acid | | 3 | 2.41 | 4 | 4.27 |
| Heptacosane | a | 5 | 1.85 | 6 | 1.80 |
| Tetracosanol (TMS) | a | 6 | 3.02 | 7 | 1.50 |
| Hexacosanal | | 7 | 1.61 | 8 | 1.57 |
| Nonacosane | a | 8 | 21.16 | 9 | 21.39 |
| Hexacosanol (TMS) | a | 9 | 14.51 | 10 | 6.30 |
| Heptacosanol + Octacosanal | | 10 | 11.27 | 11 | 5.63 |
| Nonacosan-15-one (TMS) | a | 11 | 24.19 | 12 | 23.19 |
| Octacosanol (TMS) | a | 12 | 2.62 | 13 | 2.02 |
| Nonacosanol (TMS) | a | 13 | 3.22 | 14 | 2.02 |
| α + β amyrin | | 14 | 5.64 | 15 | 11.03 |
| Phthalates | b | 1/4 | 3.60 | 2/5 | 7.20 |

a. Also reported by Purdy and Truter (1963) as components of cabbage wax.

b. Contaminant

Table 10.17 presents the quantitative comparison of the TLC separations of wax constituents of control and ethofumesate treated plants. Individual fractions were easily detected under UV-infra red spectra. Although all constituents moved easily to the non-polar solvent front, chloroform extract separated better than methanol extract.

Table 10.17 Comparison of Rf values of major components of leaf wax extracted from leaves of untreated (Control) and pentane treated (Pentane) cabbage plants.

| Fraction/ class | Methanol extract | | b Chloroform extract | |
|---|---|---|---|---|
| | Control | Pentane | Control | Pentane |
| Paraffins (Alkanes) | 0.93 | 0.90 | 0.90 | 0.95 |
| Alkyl esters | 0.90 | ... | ... | ... |
| Alkyl ketones | 0.87 | 0.81 | 0.84 | 0.83 |
| Unknown | - | - | 0.68 | - |
| Secondary alcohols | 0.46 | - | 0.42 | 0.43 |
| Primary alcohols | 0.12 | 0.12 | 0.13 | 0.14 |
| Fatty acids | 0.00 | 0.00 | 0.0 | 0.0 |

b Solvent system = Benzene-chloroform (7:3 v/v)

- : Fraction absent, ... = Unidentified fraction.

Diagnostic zones were based upon differential absorption under UV - infra red spectra.

Analysis of the constituents of fraction no. 6/7 of the wax extracts showed that ethofumesate treatment induced a marked decrease in the levels of acids, aldehydes and ketones. Nonanal was entirely absent in wax inhibited plants (Fig. 10.8, Table 10.18).

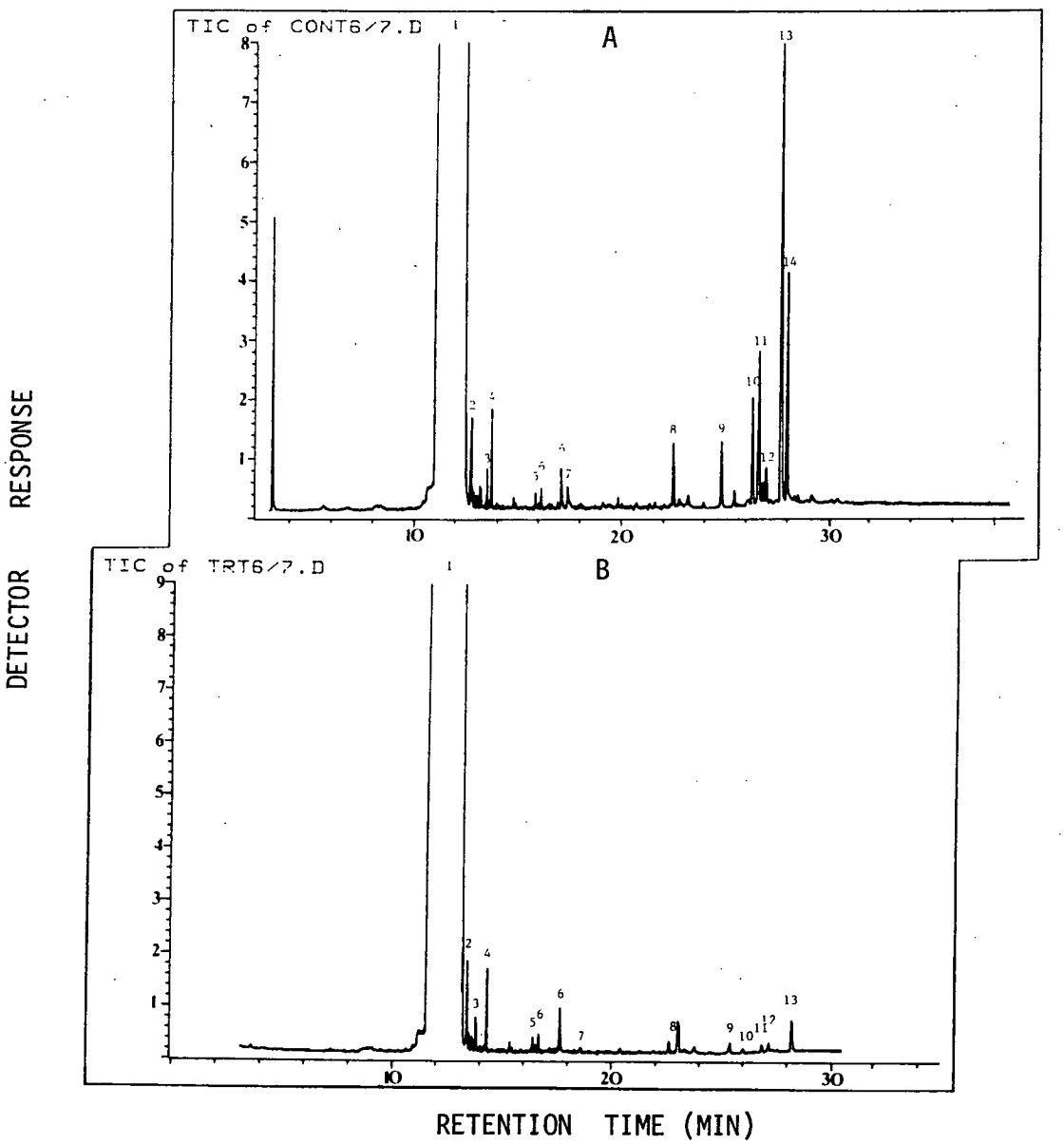



Fig. 10.8. Chromatogram of the No.7 fraction of the surface wax from untreated (A) and ethofumesate treated (B) cabbage plants. For identification of peaks see Table 10.12.

Table 10.18 Identification and relative abundance of the constituents of the fraction no. 6/7 from the surface wax of untreated (Control) and ethofumesate treated (Tramat) cabbage plants.

| Identification | Control | | Tramat | |
|---|---|---|---|---|
| | Peak no. | Relative abundance (%) | Peak no. | Relative abundance |
| Tetradecane * | 1 | Area 198= 1953443 | 1 | Area 198= 2128667 |
| Unidentified base peak m/z 71 | 3 | 2.68 | 3 | 9.34 |
| Palmitic acid | 7 | 1.46 | 7 | 0.93 |
| Squalene | 9 | 4.64 | 9 | 2.80 |
| Octacosanal | 10 | 7.82 | 10 | 1.86 |
| Nonacosan-15-one | 11 | 10.51 | 11 | 1.86 |
| Nonanal | 12 | 2.44 | - | - |
| Triacontanal | 13 | 31.54 | 12 | 7.47 |

* Tetradecane used as internal standard.

In the Fig. 10.8 Pentadecane, hexadecane and octadecane (peak no. 2, 4 and 5 respectively) probably derived from tetradecane degradation. Peak 6 and 8 were phthalate contaminants and peak 14 in control was an unknown syringe artifact.

10.3.10 Evaluation of solvent sprays in field trials

The suppression of normal pest behaviour by solvent sprays was also demonstrated in the field. There were relatively lower CA colonization and reproduction and CWB oviposition on plants sprayed with pentane and/or petroleum ether compared with commercially sprayed plants (Table 10.19). A slight burning of tissues in outer leaves was observed in pentane treated plants but this did not affect the overall marketability of the harvested heads. Material costs were the highest in pentane treatment followed by pentane+petroleum ether>commercial sprays.

In the second field test, the costs of petroleum ether sprays were the lowest among all treatments (Table 10.20). The numbers of spray applications required were 4, 4, 7 and 5 for pentane, petroleum ether, pyrethrum and the commercial application, respectively. Pest numbers were markedly lower on solvent sprayed plants compared with pyrethrum and commercial spray applications. In this test, phytotoxic effects were minimized by the use of controlled droplet application methods. The results show that using action threshold criteria at least one spray application was saved without any significant decline in the marketable yield.

Table 10.19 Pest pressure, control costs and performance of cabbage plants treated with experimental solvents and commercial insecticide spray schedules (March-June 1984).

| Treatment | No. sprays | Material/toxicant cost/spray/ha $ | Total Cost $ | Pest density/30 plants | | | | | Performance (Kg=$\bar{X}$±S.E.) | | Marketability % |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | *A | N | Ratio A:N | E | L | Total wt. | Commercial wt. | |
| | | | | | | | | | y | | |
| Pentane | 4 | 169.92 | 697.68 | 119 | 329 | 1:2.7 | 7 | 4 | 2.53±0.13 a | 1.05±0.07 a | 93 |
| Pentane + Petroleum ether | 4 | 169.92 + 16.80 | 373.44 | 116 | 322 | 1:2.8 | 4 | 2 | 2.83±0.17 a | 1.30±0.08 b | 93 |
| **Commercial | 4 | 20.16 | 80.64 | 191 | 989 | 1:5.2 | 22 | 13 | 2.97±0.10 a | 1.53±0.08 c | 93 |

* Abbreviated as A = alate cabbage aphid, N = apterae, E = butterfly eggs, L = butterfly larvae.

** Toxicants consisted of thiometon (Ekatin) and permethrin (Ambush) applied by the commercial grower.

y Means with the same letter are not significantly different ($p \geq 0.05$, Duncan's multiple range test).

Table 10.20 Pest pressure, control costs, performance and marketability of cabbage treated with experimental solvents and commercial insecticides (January-April 1985).

| Treatment | No. sprays | Material/toxicant cost/spray/ha $ | Total Cost $ | Pest density/25 plants * A | N | Ratio A:N | E | L | Performance (Kg=$\bar{X} \pm$ S.E.) Total wt. | Commercial wt. | Marketability (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Pentane | 4 | 169.92 | 697.68 | 41 | 63 | 1:1.5 | 74 | 37 | 4.42±0.34 | 2.95±0.24 | 88 |
| Petroleum ether | 4 | 16.80 | 67.20 | 34 | 80 | 1:2.3 | 51 | 35 | 4.52±0.31 | 2.92±0.19 | 96 |
| Pyrethrum | 7 | 39.40 | 275.80 | 72 | 302 | 1:4.2 | 134 | 55 | 5.22±0.26 | 3.44±0.18 | 96 |
| ** Commercial | 5 | 20.16 | 100.8 | 91 | 231 | 1:2.5 | 137 | 61 | 4.8±0.29 n.s. | 3.29±0.22 n.s. | 92 n.s. |

* Abbreviated as A =alate cabbage aphid, N = apterae, E = butterfly eggs, L = butterfly larvae.

** Toxicants consisted of thiometon (Ekatin) and permethrin (Ambush) applied in combination by the market gardener.

n.s. Not significantly different ($p \gg 0.05$, Duncan's multiple range test).

## 10.4 Discussion

Significant suppression in insect pest numbers was achieved by conditioning cabbage plants with solvent sprays. To date, there is a general consensus that alteration of the host quality may modify choice by insect pests (Rhodes, 1979; Myers, 1985; Bernays and Lewis, 1986). However, there have been no studies to show that either solvent treatment or wax inhibitor may induce certain changes in the physical or chemical characteristics of the host plant that subsequently confer resistance against pest attacks.

Generally the behaviour of insects involves an extensive sensory investigation of host surface before showing any decision response (Blaney and Chapman, 1970; Chapman, 1982). Thus, leaf surface characteristics may provide information on the suitability of the leaf as a potential food. Dethier (1970) stated that ;

> "the first barrier to overcome in the insect plant relationship is a behavioural one. The insect must sense and discriminate before nutritional and toxic factors become operative".

The apparent deterrent effect of the infested/damaged plants to other species was mimiced by solvent treatments causing a significant suppression of normal insect behaviour. The basis of this suppression was exhibited in the form of disorientation of epicuticular wax bloom on the leaf surface as well as alterations in plant physiology i.e. water stress, stomatal closure, variations in volatile and wax constituents. The results show that these changes were potent enough to account for the

suppression in insect behaviour and the phenomena involved provide a potential approach to induce resistance in plants against insect pests.

The ovipositional behaviour of CWB includes an approach flight, subsequent landing and drumming of the upper leaf surface with the front legs, consecutive curving of the abdomen and finally oviposition on the lower leaf surface of preferably outer leaves. Neonate larvae feed directly on suitable foliage until their development into the pupal stage. Similarly, DM female lays eggs singly or in small groups mainly on the upper surface of leaves. Neonate larvae after burrowing the leaf surface feed on mesophyll tissues. The older larvae either feed on the leaf surface or tunnel into the tissues of preferably heart leaves. In contrast, CA settles on a leaf surface and initiates phloem seeking probes with deep stylet insertion beyond the epidermis in an intercellular path to locate sieve elements, the contents of which are subsequently ingested. Reproduction follows feeding (Kennedy, 1953; Wensler, 1962).

The deterrence in CWB oviposition on frass or larval extract treated plants corroborates a previous finding by Renwick and Radke (1980) that oviposition of the cabbage looper, T. ni was suppressed by the feeding of its larvae or when plants were treated with larval frass. Karban (1986) demonstrated that resistance to spider mite on cotton was induced by previous mite damage or mechanical abrasion of leaves.

The general transpiration or gas exchange is regulated

by stomatal activity (opening or closure) and it is conditioned by the properties of the plant surface i.e. chemical composition, fine structure and gross morphology (Juniper and Jeffree, 1983). In this investigation, the stomatal closure and the development of a water deficit in the outer leaves following solvent treatment may well be associated with suppression in the colonization and larviposition by CA and oviposition and larval feeding of CWB. Immediate discrimination of foliage by alighting and probing aphids could be affected by their response to water vapour has been suggested by Nault and Styer (1972). A considerable controversy exists on the effect of water stress on aphids e.g. showing restlessness or developing wings (e.g. Rivnay, 1937; Miles et al., 1982); decreased progeny production (Kennedy, 1958) increased rate of development (Miles et al., 1982) or mass multiplication (Markkulla, 1953, White, 1978, 1984). The well known effect of water stress (shortage) in the plant is the loss of cell turgor. This loss of turgor may cause reduction in food uptake (e.g. Mittler, 1958) or inhibit the supply of photosynthate. Similarly, Traynier (1984) indicated that water vapour and sinigrin are both essential for CWB oviposition and are perceived through tarsal contact.

Mustard oils or their glucosides are reported to be at least partially responsible for host selection by DM and CWB larvae (Thorsteinson, 1953; Hovanitz et al., 1963) and CA (Wensler, 1962; Moon, 1967). The volatile isothiocyanates have received more attention and were generally believed to be the major characteristic vapours

emanating from intact cruciferous plants (Matsumoto, 1970). However, in the present investigation these volatiles were either totally absent or below the limit of detection and a conclusive involvement of isothiocyanate volatiles could not be established in the present investigation. This is further supported by the fact that CWB tended to lay eggs on the outer leaves of cabbage which reportedly have less allyl isothiocyanate than inner leaves (MacLeod and MacLeod, 1970). In contrast, Renwick and Radke (1983) suggested that two or more non-volatile chemicals are needed for stimulation of oviposition and selection of oviposition sites. Terofal (1965) considered that volatilized mustard oil glucosides do not release egg laying behaviour and oviposition is only performed in response to chemical contact stimuli (see also Traynier, 1979).

The suppressed level of dimethyl disulphide, a typical cabbage flavour volatile (Dateo et al., 1957) in the solvent treated plants may have an important bearing on the insect behaviour. The relative abundance of this volatile was found to be much more than 0.5% as reported by Buttery et al. (1976). An aldehyde fraction, nonanal, was interestingly present in collected volatiles whereas Buttery et al. (1976) reported its complete absence in cabbage. This volatile has been identified as a major component in the aldehyde fraction of epicuticular wax of plum (Ismail et al. 1977). If insect behaviour is influenced by the volatiles emanated from the host, any variation in their amount or nature may considerebly

modify the normal insect's response to the host.

The evidences presented in this study show that the surface wax of cabbage leaf is a highly complex chemical environment. Nevertheless, the suppression in pest numbers/behaviour was significantly associated with the decline in the levels of the major wax components i.e. alkanes, ketones, alcohols and aldehydes in the solvent or ethofumesate treated plants. This finding suggests that the wax constituents of cabbage leaf surface are perceived by specialist/monophagous insects and play a major role in their host selection and subsequent utilization. Interestingly, Chapman (1977) reported that when surface wax from non-host brassica plants was removed, the plants were no longer rejected by Locusta spp., a general herbivore.

The suppression of nonacosane and nonacosane-15-one which make up 93% and 73% of alkane and ketone fraction of the cabbage wax respectively (Purdy and Truter, 1963 c) may well inhibit the chain elongation of fatty acids in the elongation-decarboxylation pathway of epicuticular wax synthesis (e.g. Leavitt et al., 1978). The absence of nonacosane and nonacosan-15-one has been associated with the resistance of white mustard, Sinapis alba L., to CA (Chibnall and Piper, 1938). Other accounts of resistance to CA through "non-waxiness" have been made by Thompson (1963).

The marked increase in the levels of the triterpenoids $\alpha$ + $\beta$ amyrin in treated plants is of particular interest. Although triterpenoids have been reported as feeding

deterrent for various polyphagous acridids (Kogan, 1976), it is possible that increased levels of these compounds may override the stimulatory effect of other excitatory substances in the leaf surface environment. Holloway and Challen (1966) have reported the existance of β amyrin in brassica wax. The finding by Renwick and Radke (1981) on host plant constituents as oviposition deterrent for the cabbage looper suggests that plant suitable for feeding by a particular insect may also contain compounds that may deter its selection (i.e. oviposition, etc.) by that insect. Further studies are however, needed to enable a firm statement to be made.

Enhanced CWB oviposition on plants treated with water extracts of control plants are analogous to previous studies by Ives (1978) which showed that CWB oviposition was mediated by chemoreception/mechanoreception of characteristics of the host leaves. The additive effect of polar constituents (e.g. sinigrin) is sufficient to suggest that the disorientation of plant surface wax layer or the altered physiological condition resulted in suppressed CWB behaviour (see also Renwick and Radke, 1983). However, the failure of the water extracts of control plants to enhance CA larviposition suggests that CWB and CA have different strategies of host selection. Consistent suggestion was made by Moon (1967) that the role of water soluble sinigrin is more that of an arrestant rather than as a phagostimulant. The results in the present investigation agree with this suggestion where water extracts of cabbage leaves significantly enhanced CA

colonization but not larviposition. However, the enhanced effect of methanol (polar) and chloroform (apolar) extracts of control plants on CA larviposition does not explain whether the treated leaves stimulated prolonged ingestion or altered the physiology of the treated leaves.

The phenomena of suppression of pest numbers by solvent treatment was successfully demonstrated in commercially grown cabbage fields. Despite the potential risk involved in the use of inflammable solvents, their field performance to suppress pest numbers more than offset this disadvantage through cost effectiveness depending on the solvent employed. However, with improved methods, the material cost and number of applications were less than the conventional pesticidal control operations.

The inducible effect of conditioning of host plant has potential application in the suppression of pest numbers without detrimental effect on associated biotic agencies.

# CHAPTER 11

# CONCLUSION

Tasmanian cabbage crops are attacked by three major insect pests, the cabbage aphid, diamondback moth and cabbage white butterfly. Infestations affect grower's returns in two ways namely :

1. reduction in potential productivity and
2. contamination, burrowing, etc., which lowers cosmetic appearance and hence market value.

Although no single census method was absolutely efficient in satisfying standards of sampling for all species and individual stages including parasitoids, the direct count method provided the most informative and reliable estimates in relation to cabbage growth and phenology of development. Taylor's regression method most accurately described dispersion characteristics for all pests.

Direct counts supplemented by sticky traps for parasitoids and pheromone traps for diamondback moth provided a valid appreciation of the dynamics of all pests.

Temperature was the most important environmental factor influencing both the pests and cabbage growth and the concept of physiological heat units permitted the prediction of numbers of generations and pest population growth relative to the different growth stages of the cabbage plant which, inturn, influenced the incidence and

severity of damage. Cabbage plants have the capacity to compensate for damage during the active leaf expansion stage while the post seedling, cupping and heading stages were the most sensitive to attack.

No pest was effectively controlled by biotic agents and the applied usage of entomopathogenic nematodes, bacteria (Dipel) and fungi, though markedly effective under laboratory conditions, were of little value in the field. This failure was due to negative (unfavourable) environmental factors e.g. low relative humidity, poor dispersal and the cabbage structure which provided protected feeding sites, particularly for diamondback moth and cabbage aphid.

Pest populations were influenced markedly by the frequency of irrigation which affected plant growth and in the case of overhead irrigation the dislodgment of larvae, aphids, etc. In addition, failure to remove crop residues and stubbles and cruciferous weeds ensured a resident pest population between crops and seasons.

In general, the demand for a product of good appearance tends to promote excessive spraying. Spray application decisions based on action thresholds have been shown to reduce the number of applications by more than 50 percent. Better pest control by commercial growers is possible only through their education to appreciate both crop plant and pest insect. Generally, cabbage plants require protection during the vegetative phase to maximize yield and during head formation to enhance cosmetic appearance.

Non-preference was shown to be the most effective form of resistance with lepidopterous pests rejecting plants that were less waxy or more glossy. The basis of this preference was partly explained by experimental alteration or disruption of leaf surface wax which strongly inhibited oviposition/larviposition. Chemical analyses of treated plants suggest that the triterpenoids $\alpha + \beta$ amyrin may effectively deter lepidopterous oviposition while alteration of water status (excessive transpiration) minimizes larviposition by cabbage aphid by suppressing settling and feeding on stressed plants. These interpretations are contrary to other explanations of cabbage-insect interaction which emphasize mustard oil glucosides as key determinents. In this investigation, the occurrence of these compounds was rare and of low intensity.

A re-examination of the use of pest resistant cultivars in cabbage pest control is required while the low tolerance threshold for pests by industry and consumers could be relaxed if consumer demand was based on value per item rather than appearance per item.

In the light of this study an effective pest control strategy against cabbage pests in Tasmania must involve :

(a) regular inspection of cabbage crops ;

(b) spray applications to post seedling, cupping and pre heading growth stages if and when the pest numbers, as measured by an action threshold, demand control measures ;

(c) employment of effective materials preferably

systemic (pirimicarb) and contact(permethrin) insecticides in combination ;

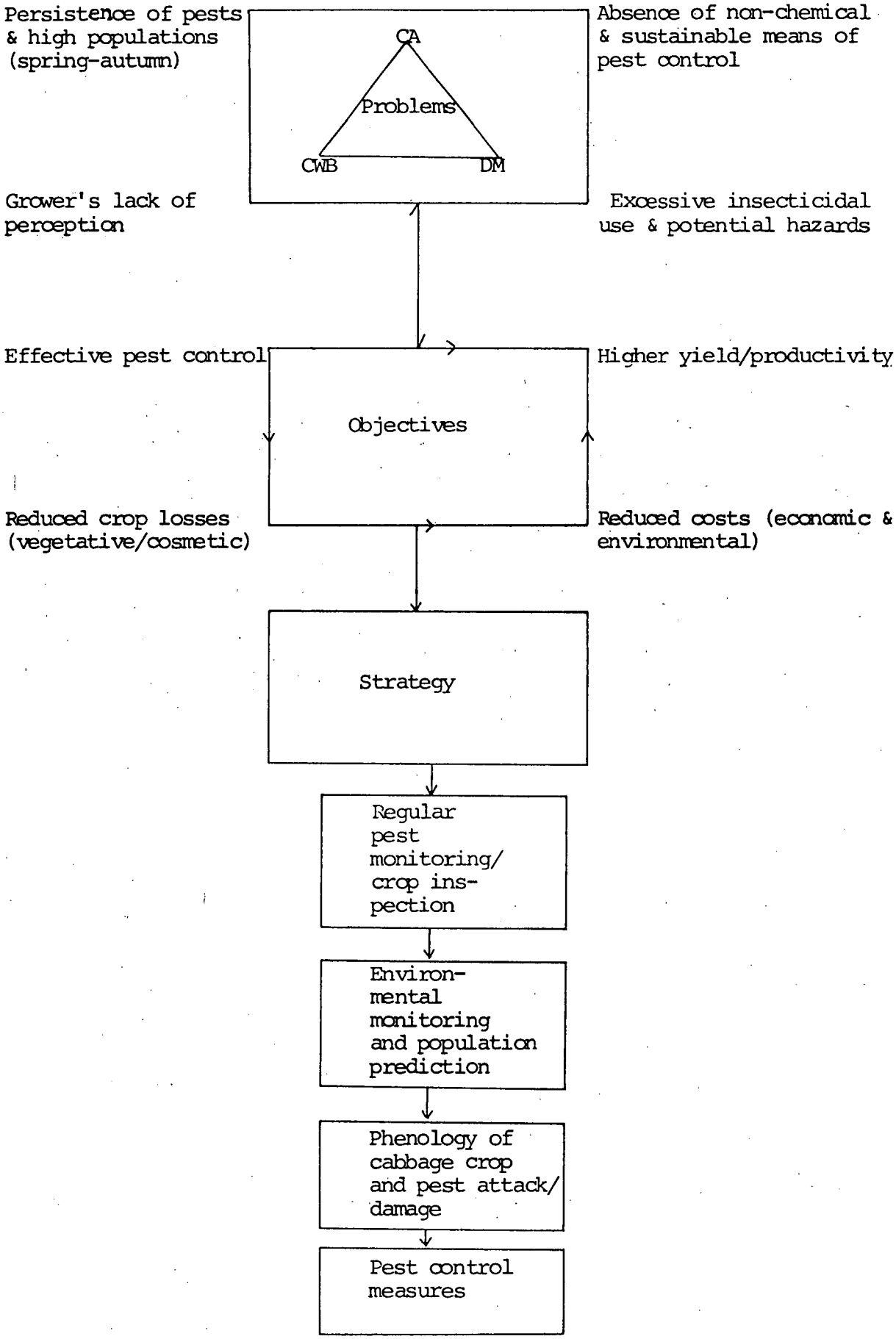
(d) provision of information on pest status and potential to the growers by monitoring of pests in brassica vegetable as well as non-vegetable (forage, oilseed) crops ;

(e) the use of resistant cultivars and

(f) destruction of alternate hosts, stubbles, crop residues, regrowth, etc.

Further research should be carried out on the induction of non-preference in crop plants by the use of solvent and wax inhibiting materials. Such work has possible application to other pest-plant relations e.g. chrysomelid infestations of Eucalyptus spp. which are also characterized by waxy leaf surfaces.

# IPM STRATEGY OF CABBAGE CROPS IN TASMANIA



## ACTION PLAN (MODUS OPERANDI)

1. **Regular pest monitoring/ crop inspection**

- Direct counting of the young stages (eggs, larvae, pupae) of CWB/DM and alate and apterae of CA on cabbage plants.
- Flight monitoring of CA alates by Moericke traps (September-February) and DM months by pheromone traps (September-February)
- Monitor pest attack in the surrounding brassica forage crops (spring-autumn)

2. **Environmental monitoring and population prediction**

- Monitor temperature (heat units) and predict population maxima and no. of generation(s).

| Pest | Generation time HU's | No. of generations/year |
|---|---|---|
| CA | 223±13.5-233±14.6 | 13 |
| CWB | 231±20 | 5 |
| DM | 306±9.5 | 5 |

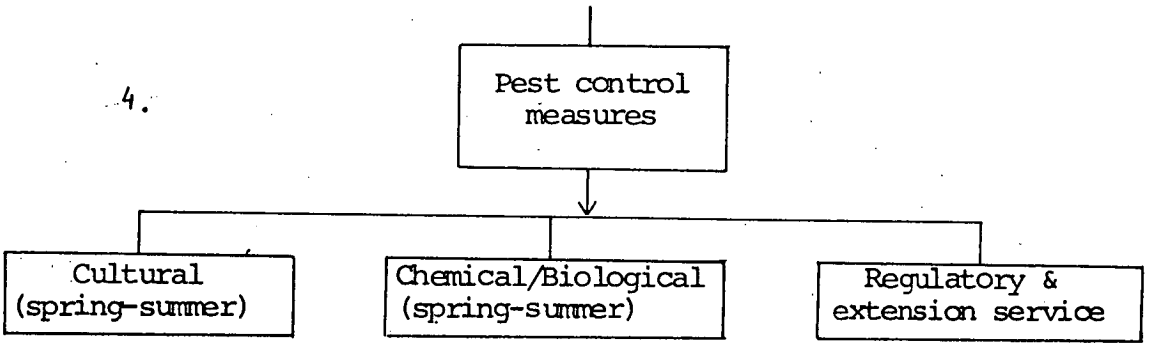
- Monitor early spring aphid mortality due to entomopathogenic fungus as high humidity and low temperature enhances fungal epizootic.
- Monitor South-Easterly wind influence on the emigration of DM/CA alates from the Mainland to Tasmania.

3. **Phenology of cabbage crop and pest attack/ damage**

- Monitor crop development from seedling-heading stages (6 growth stages require 2200 $D_0^{8.15}$ ).
- Protect vegetative phase (seedling-cupping) to protect yield factors and final productivity of cabbage plants.

- Protect heading phase to meet the associated cosmetic standards of the consumers (e.g. removal of infested/damaged wrapper leaves from the cabbage heads).

4.




## 1. Cultural Control

- Destroy stubbles and regrowth from the cut stems
- Destroy cruciferous weeds in the area
- Use over-head sprinkler irrigation for the dislodgment of CA and DM stages.
- Employ non-waxy and glossy cabbage cultivars.

## 2. Chemical/Biological Control

- Spray application of systemic insecticides (pirimicarb, demeton-s-methyl etc.) against aphids when $\geq$ 5/plant
- Spray contact insecticides (maldison, permethrin etc.) against CWB/MD larvae when $\geq$ 0.1/plant
- Don't use heavy sprays just after transplanting
- If pest density is $\geq$ action threshold:

  * Spray application of pirimicarb / demeton-s-methyl against CA in post-seedling and pre-heading stages.
  * Spray application of permethrin / B.t. against CWB larvae in cupping stage.
  * Spray application of permethrin against DM larvae in seedling and pre-heading stages.

3. Regulatory and Extension Service

Market stability

- Stable pricing system of cabbage produce at the wholesaler / retailer levels.
- Need-oriented advice on the pesticidal use and the rejection of intensive and insurance spray policy / practice.
- Introduction of selective pesticides by the pesticide companies.

Extension service

- Regular pest scouting by the research and extension staff of the State Department of Agric. and the provision of good information on when and what to apply for effective pest control and as a result avoid unnecessary application of pesticides.
- Educate cabbage growers to utilize economic thresholds of pests for decision-making.
- Educate consumers to adopt a low-pest tolerance attitude.

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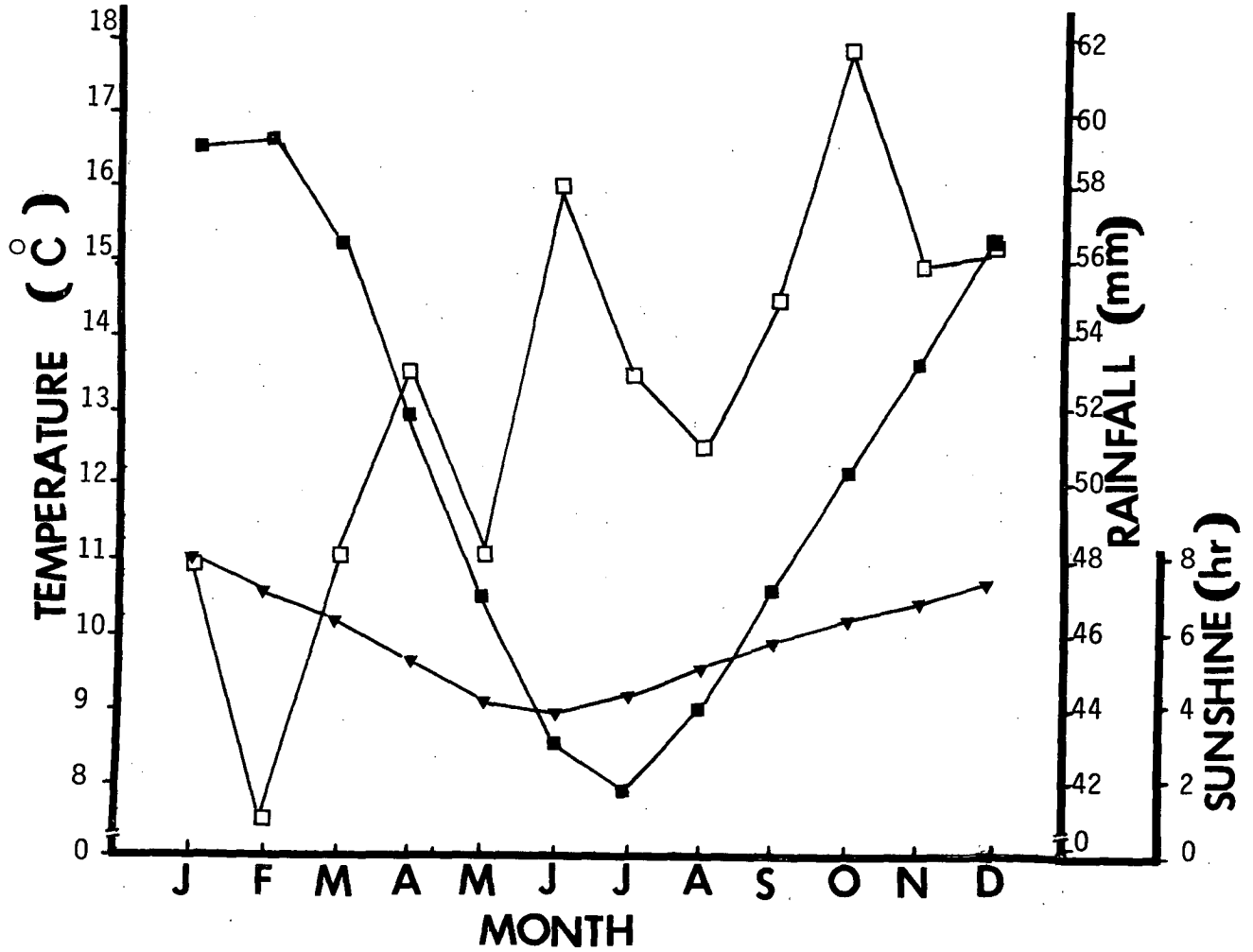
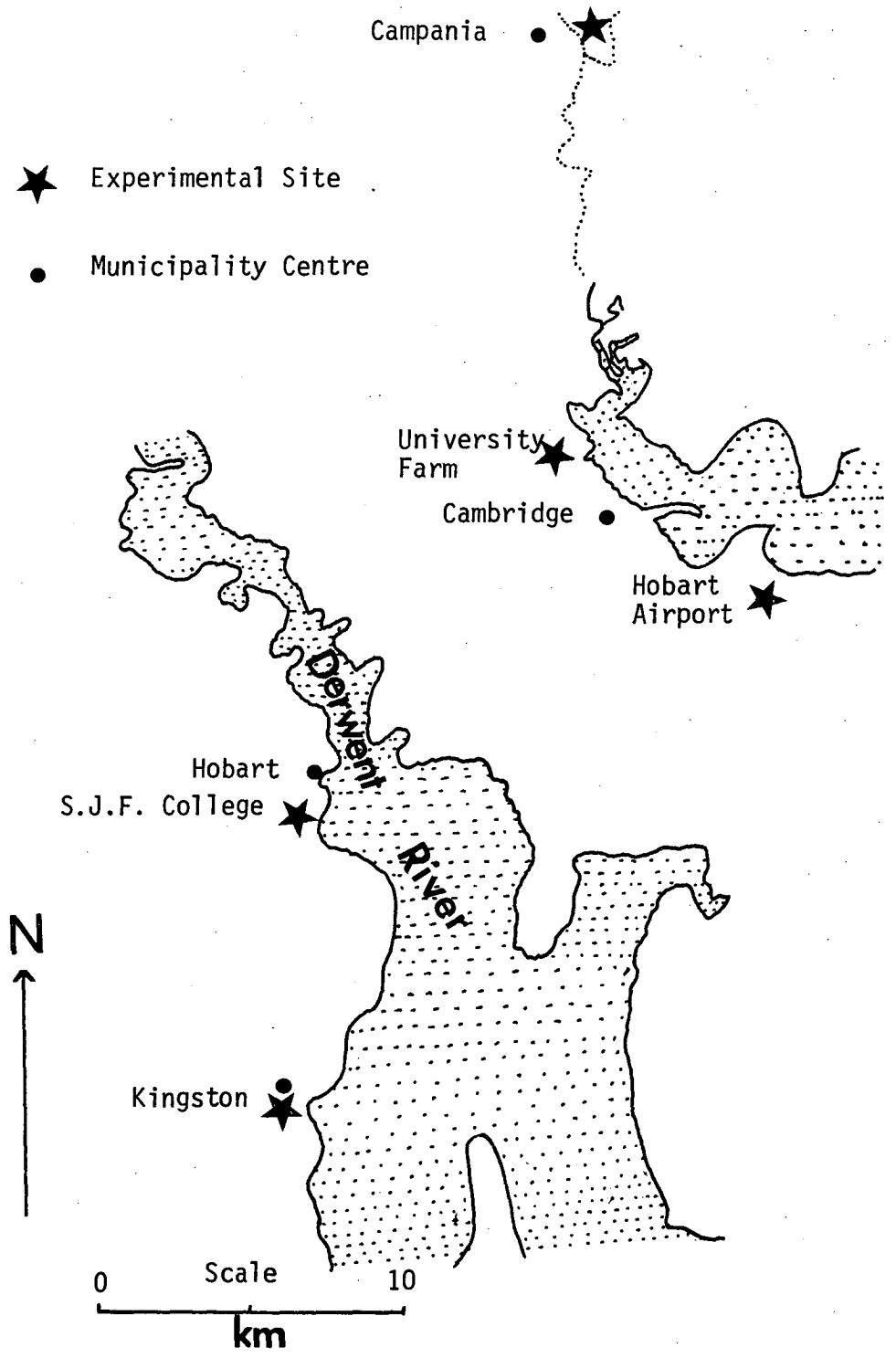
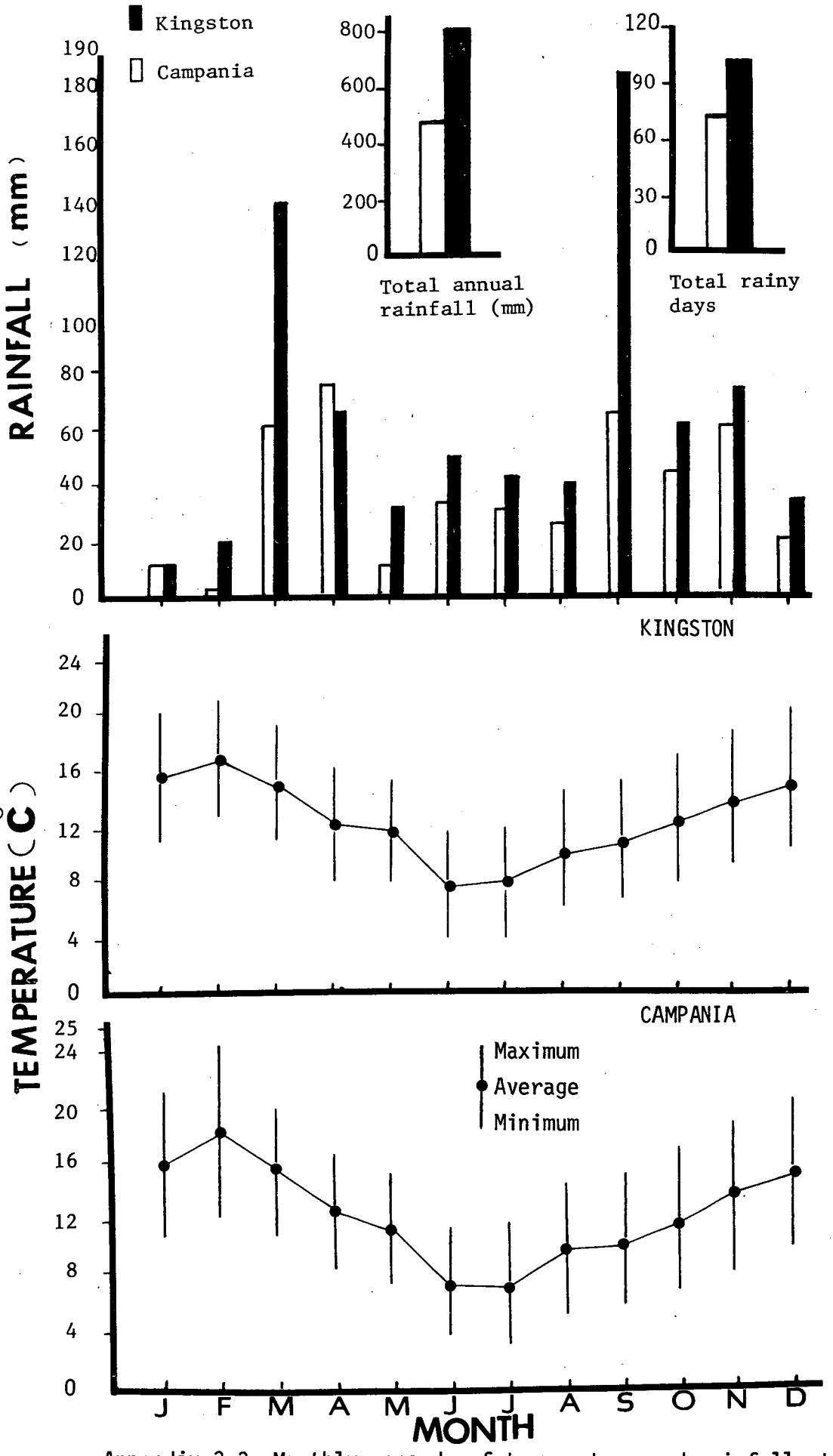
# A P P E N D I C E S




Appendix 3.1. Ninty nine years means of average monthly temperature (■) monthly rainfall (□) and daily sunshine (▲) at Hobart ( Source : Bureau of Meteorology, Hobart ).

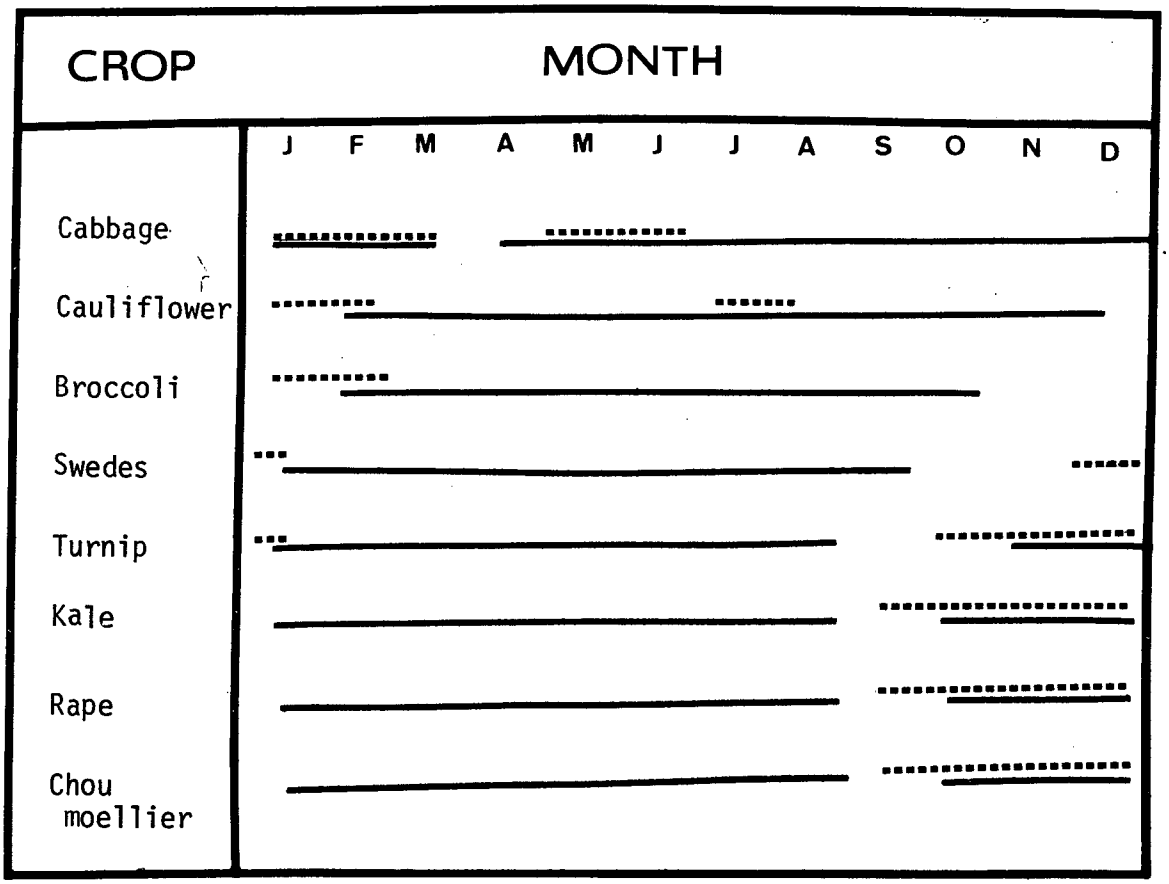



Appendix 3.2. Locality map of the study area showing selected sites.




Appendix 3.3. Monthly records of temperature and rainfall at Kingston and Campania during 1983.

Appendix 3.4. Synchrony of the growth periods of Brassica vegetables and forage crops and their availability in/around the experimental area for possible pest attack.



Appendix 4.1 Formulation and preparation details of the sticky paste used on sticky traps.

| Ingredient | % W/W | Supplier * |
|---|---|---|
| Cereclor A42 | 89.60 | 1 |
| Alloprene R90 | 0.35 | 1 |
| Carnauba Wax | 1.45 | 2 |
| Candellia Wax | 2.50 | 2 |
| Camphor Oil | 4.90 | 2 |
| Fluorescein-Sodium Salt (1% aqueous) | 1.20 | 3 |

* 1 ICI Dyestuffs, 69 Macquarie St., Sydney, N.S.W. 2000.

2 Bronson & Jacobs, 288 Burnsbay Rd., Lane Cove, N.S.W. 2066.

3 Sigma Chemical Company, P.O. Box 14508, St. Louis, MO 63178 U.S.A.

Preparation

1. All ingredients were placed into a 2-l glass beaker heated, and stirred till dissolved.

2. Temperature was maintained at 90°C during stirring.

3. Material was poured into glass container and stored at room temperature till used.

## Appendix 10.1 Technical details of the systems used for the collection and identification of cabbage volatiles.

### 1. Collection of Volatiles

Collection tubes (traps) consisting of 170mm lenght of glass lined stainless steel tubing (6mm outer diam., 4mm inner diam.) were previously baked at 400°C and packed with 0.4g Tenax G.C. 35/60 MESH No. 4899 (Alltech Associates, Inc. IL. USA 60015). Traps were pre conditioned at 275°C for 24h in a stream of high purity N in the Chemistry Department, University of Tasmania and held in stoppered glass containers with small amount of dried silica gel granules to absorb any water molecules in the container. Purified air (Zero Grade, Gas code No. 055 CIG Australia) was passed over the foliage in the collection chamber.

### 2. Identification of Volatiles

The combined GC-MS facility at the CSL consisted of a Pye Unicam 204 chromatograph coupled directly via a glass lined steel tube, gas (helium) flow rate 2mls/min heated at 200°C to a vaccum generator (VG) micromass 7070 mass spectrometer. The spectrometer was a high resolution, double focussing model operated at an ionising energy of 70 eV at 4Kv accelerating voltage and an ion source temperature of 200°C. The GC column used was 25mX0.2mm BPI programmed from ambient at 6/min. The scanning range m/z was 300 to 20 cycling every 1.5 sec. Gas chromatograph was represented by total ion current (TIC) change with time.

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## Appendix 10.2 GC-MS system for the identification of epicuticular wax components of cabbage leaves.

The system employed for the identification of different fractions of wax components of cabbage leaves consisted of a Hewlett-Packard 5890 gas chromatograph equipped with on column injector 25mX0.3mm BPI adjusted with an open split interface (300°C). The temperature programme was 30 to 220°C at 30C/min and then upto 310°C at 8°C/min. The helium gas flow rate was 2 mls/min. The sample volume of each fraction was 0.4ul in hexane.